Appendix 3B

Regional Haze in the Upper Midwest: Summary of Technical Information

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Summary of Technical Information

Voyageurs National Park

Photo Courtesy of Chris Holbeck,
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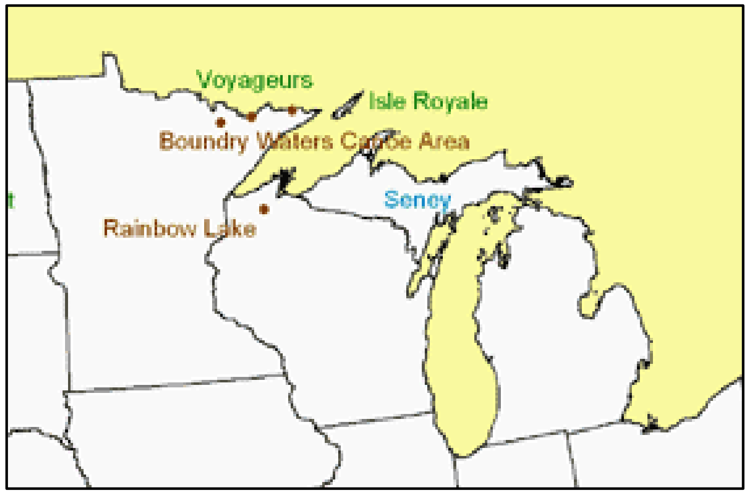
Scope of Document

This document provides a summary of available technical information about regional haze and visibility impairment in the four northern Class I areas: Boundary Waters Canoe Area Wilderness, Voyageurs National Park, Isle Royale National Park, and Seney Wilderness Area. This information includes a conceptual model of haze, the technical basis for visibility analysis, and the effectiveness of control measures in improving visibility. The document represents the technical information agreed to by the responsible states and satisfies, in part, the consultation requirements of the Regional Haze Rule. The document does not address policy issues and strategies necessary to deal with regional haze. States can use this technical information to highlight the relevant issues for their state policymakers.

Executive Summary

The States of Michigan and Minnesota, along with representatives of other states, tribal governments, and federal agencies[1], are working to address visibility impairment due to regional haze in four northern Class I areas: Boundary Waters Canoe Area Wilderness, Voyageurs National Park, Isle Royale National Park, and Seney Wilderness Area. Pursuant to the Clean Air Act, states are required to make reasonable progress toward meeting a national goal of natural conditions (i.e., visibility levels in the absence of manmade air pollution).



Class I areas in Michigan and Minnesota[2]

Based on a review of technical information, several key findings should be noted:

- The chemical species which affect visibility impairment include ammonium sulfate and, to a lesser degree, ammonium nitrate and organic carbon.

- The pollutants and source sectors which contribute the most to visibility impairment include SO2 emissions from electrical generating units (EGUs) and certain non-EGUs, which lead to sulfate formation, and NOx emissions from a variety of source types (e.g., motor vehicles), which lead to nitrate formation. Ammonia emissions from livestock waste and fertilizer applications are also important, especially for nitrate formation. (Organic carbon concentrations are thought to be mostly secondary organic aerosols of biogenic origin and, on an occasional episodic basis, from fire activity.)

- The source regions which contribute the most to visibility impairment are the States of Michigan, Minnesota, and Wisconsin. Other nearby states, including Illinois, Indiana, Iowa, Missouri, and North Dakota, also contribute to visibility impairment.

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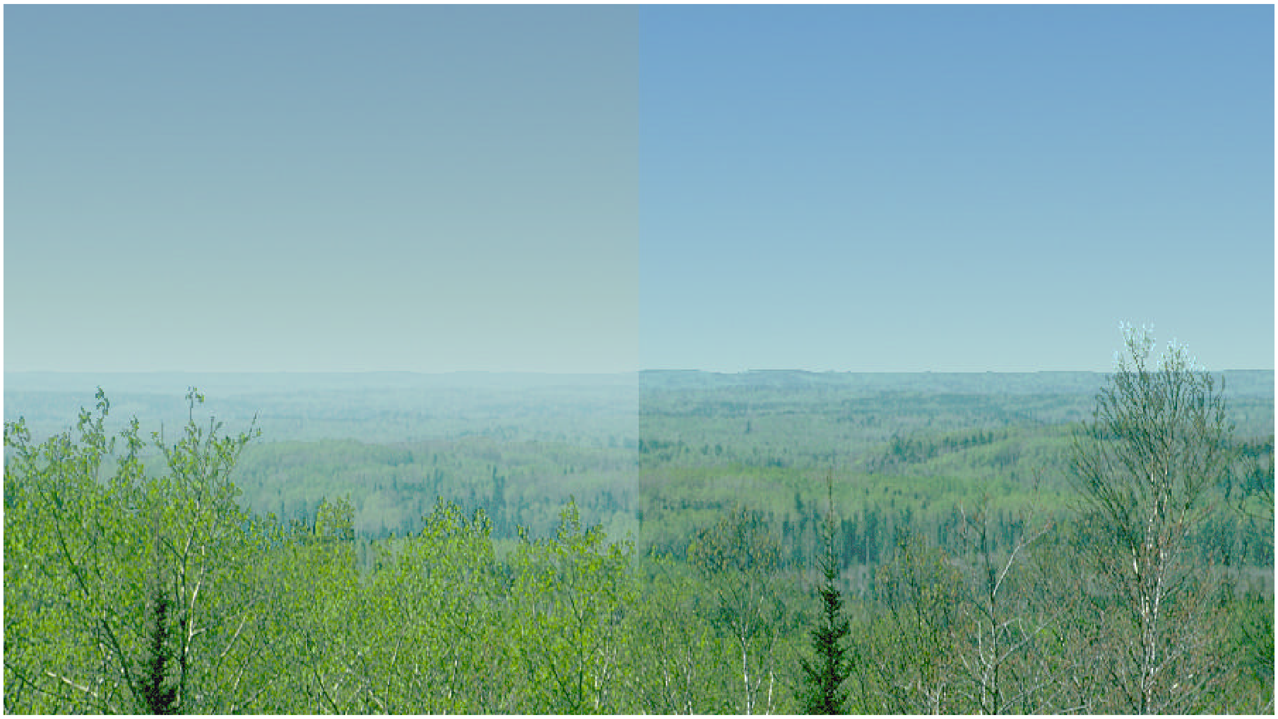
[1] Representatives from the following entities are participating in the northern states Class I area consultation process: States of Minnesota, Michigan, Wisconsin, North Dakota, Iowa, Missouri, Illinois, and Indiana; Ontario Ministry of Environment; Mille Lacs, Fond du Lac, Grand Portage, and Leech Lake Tribes; and U.S. Forest Service, U.S. National Park Service, and U.S. EPA.

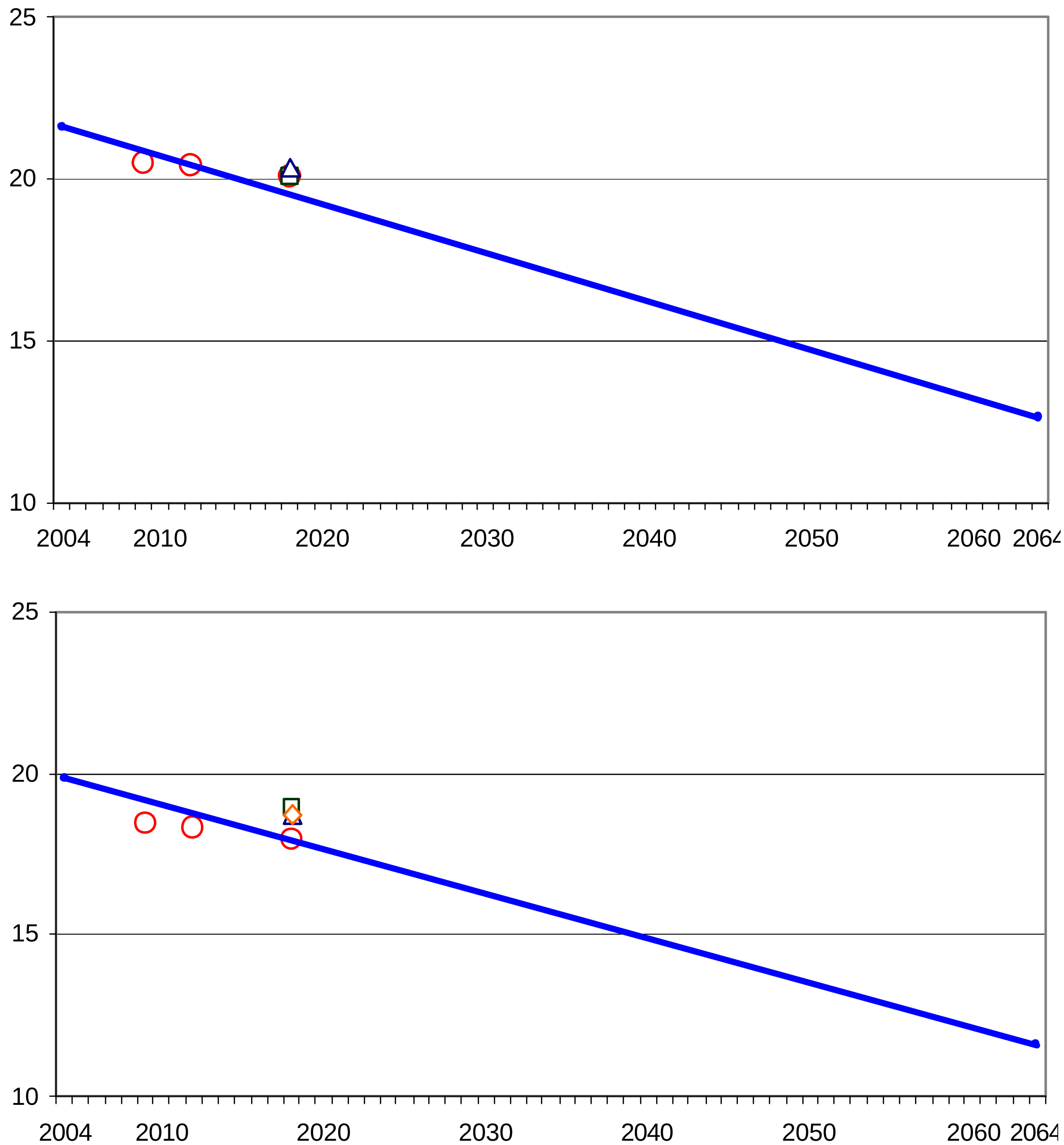
[2] Although Rainbow Lake in northern Wisconsin is also a Class I area, the visibility rule does not apply because the Federal Land Manager determined that visibility in is not an air quality related value there.

- Current (baseline) visibility levels are well above natural conditions (see, for example, picture below for Boundary Waters Canoe Area).



Boundary Waters Canoe Area – current visibility conditions on 20% worst days (left side) and the natural conditions goal (right side)

- Projected near-term visibility conditions based on existing ("on the books") controls are close to or above the uniform rate of visibility improvement line (see figure below). The regional haze rule calls for Class I areas to meet natural visibility conditions by the year 2064, with an initial implementation period extending to the year 2018. To determine whether the model-projected 2018 values (based on existing controls) represent reasonable progress, states are required to consider four factors (i.e., costs of compliance, time necessary for compliance, energy and non-air quality environmental impacts, and remaining useful life).



Projected future year visibility levels for 20% worst visibility days in Isle Royale National Park (top) and Boundary Waters Canoe Area (bottom) based on existing controls

Note: symbols represent results of four modeling analyses: LADCO 2005 base year - circle, LADCO 2002 base year – square, MPCA 2002 base year – diamond, and CENRAP 2002 base year - triangle

- The same particles (sulfates, nitrates, organic carbon, smoke, and soil dust) which affect visibility, are linked to serious health effects (e.g., National Ambient Air Quality Standards for $PM_{2.5}$) and environmental effects (e.g., ecosystem damage). Thus, actions to reduce levels of visibility-impairing pollutants will benefit public health and reduce certain adverse effects to the environment.

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Section 1
Regulatory Requirements

Section 169A of the Clean Air Act sets as a national goal "the prevention of any future and the remedying of any existing, impairment of visibility in mandatory Class I Federal areas which implementation results from manmade air pollution."

Section 169A requires states to "make reasonable progress toward meeting the national goal." In determining reasonable progress, states shall consider four factors:

- costs of compliance
- time necessary for compliance
- energy and non-air quality environmental impacts of compliance
- remaining useful life of any existing source subject to such requirements

On July 1, 1999, EPA adopted a regional haze rule to implement the provisions of section 169A by establishing a program to address regional haze visibility impairment (USEPA, 1999). Pursuant to the regional haze rule, the determination of reasonable progress shall also consider:

- uniform rate of visibility improvement (needed to attain natural visibility conditions by 2064) – i.e., "the line" (see, for example, Figure 5)

EPA's regional haze rule requires states to set reasonable progress goals for each Class I area which provide for an improvement in visibility for the most impaired days (i.e., 20% worst visibility days) and ensure no degradation in visibility for the least impaired days (i.e., 20% best visibility days).

The regional haze rule also requires states to develop a long-term strategy for regional haze which covers an initial implementation period extending to the year 2018. The haze State Implementation Plan (SIP) was due to EPA in December 2007. States must also submit a report to EPA every 5 years evaluating progress towards the reasonable progress goal, and submit a SIP revision by July 31, 2018 and every ten years thereafter.

Section 2
Technical Questions

1. Conceptual model of haze

   a. What are the chemical constituents that cause visibility impairment in the northern Class I areas?

      The most important chemical species are ammonium sulfate, ammonium nitrate, and organic carbon. The contribution of these species on the 20% best and 20% worst visibility days (based on 2000 – 2004 data) is provided in Figure 1. For the 20% worst visibility days, the contributions are: sulfate = 35-55%, nitrate = 25-30%, and organic carbon = 12-22%. It should also be noted that sulfate and nitrate contribute more to light extinction than to $PM_{2.5}$ mass because of their hygroscopic properties.

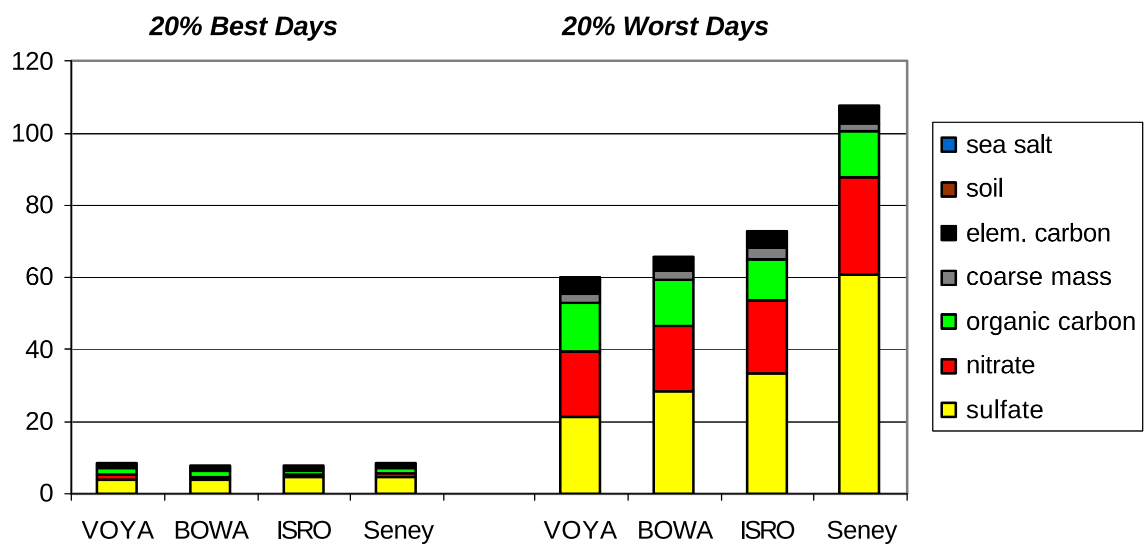

Figure 1. Chemical composition of light extinction for 20% best visibility days (left) and 20% worst visibility days (right) in terms of Mm^{-1}

   b. Which geographic areas and sources contribute to regional haze in the northern Class I areas?

      Air quality data analyses and dispersion modeling were conducted to provide information on source region and source sector contributions to regional haze in the northern Class I areas (see Appendix I: Contribution Assessment for Northern Class I Areas). Based on this information, the most important contributing states are Michigan, Minnesota, and Wisconsin, as well as Illinois, Indiana, Iowa, Missouri, and North Dakota. For example, Figure 2 presents the results of composite back trajectories for light extinction on the 20% worst visibility days. The orange areas are where the air is most likely to come from, and the green areas are where the air is least likely to come from. As can be seen, poor visibility days are generally associated with transport from regions located to the south of these Class I areas.

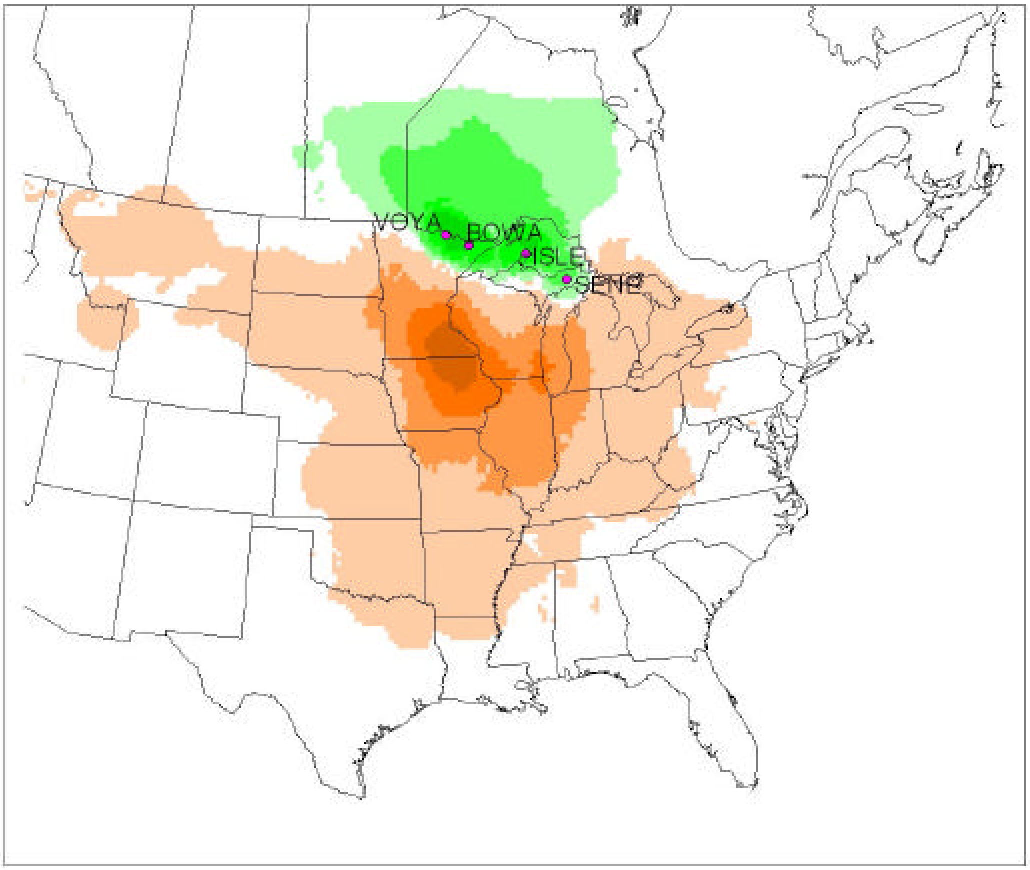

Figure 2. Composite back trajectories for light extinction
Note: orange is where air is most likely to come from, green is where air is least likely to come from

The most important contributing pollutants and source sectors are SO2 emissions from electrical generating units (EGUs) and certain non-EGUs, which lead to sulfate formation, and NOx emissions from a variety of source types (e.g., motor vehicles), which lead to nitrate formation. Ammonia emissions from livestock waste and fertilizer applications are also important, especially for nitrate formation. (As discussed below, organic carbon concentrations are thought to be mostly secondary organic aerosols of biogenic origin and, on an occasional episodic basis, from fire activity.)

c. What are the meteorological conditions that are associated with good visibility and poor visibility in the northern Class I areas? Is there a seasonal effect to visibility impairment in those areas?

As noted above, bad air days are generally associated with southerly transport (see Figure 2). Examination of the 20% worst visibility days for the northern Class I areas shows that these days occur throughout the year, suggesting a range of other meteorological parameters (see, for example, Boundary Waters data in Figure 3). This figure, as well as Figure 4 (which presents the monthly average light extinction values based on all sampling days), also show that sulfate and organic carbon concentrations are higher in the summer, and nitrate concentrations are higher in the winter, suggesting the importance of different sources and meteorological conditions at different times of the year.

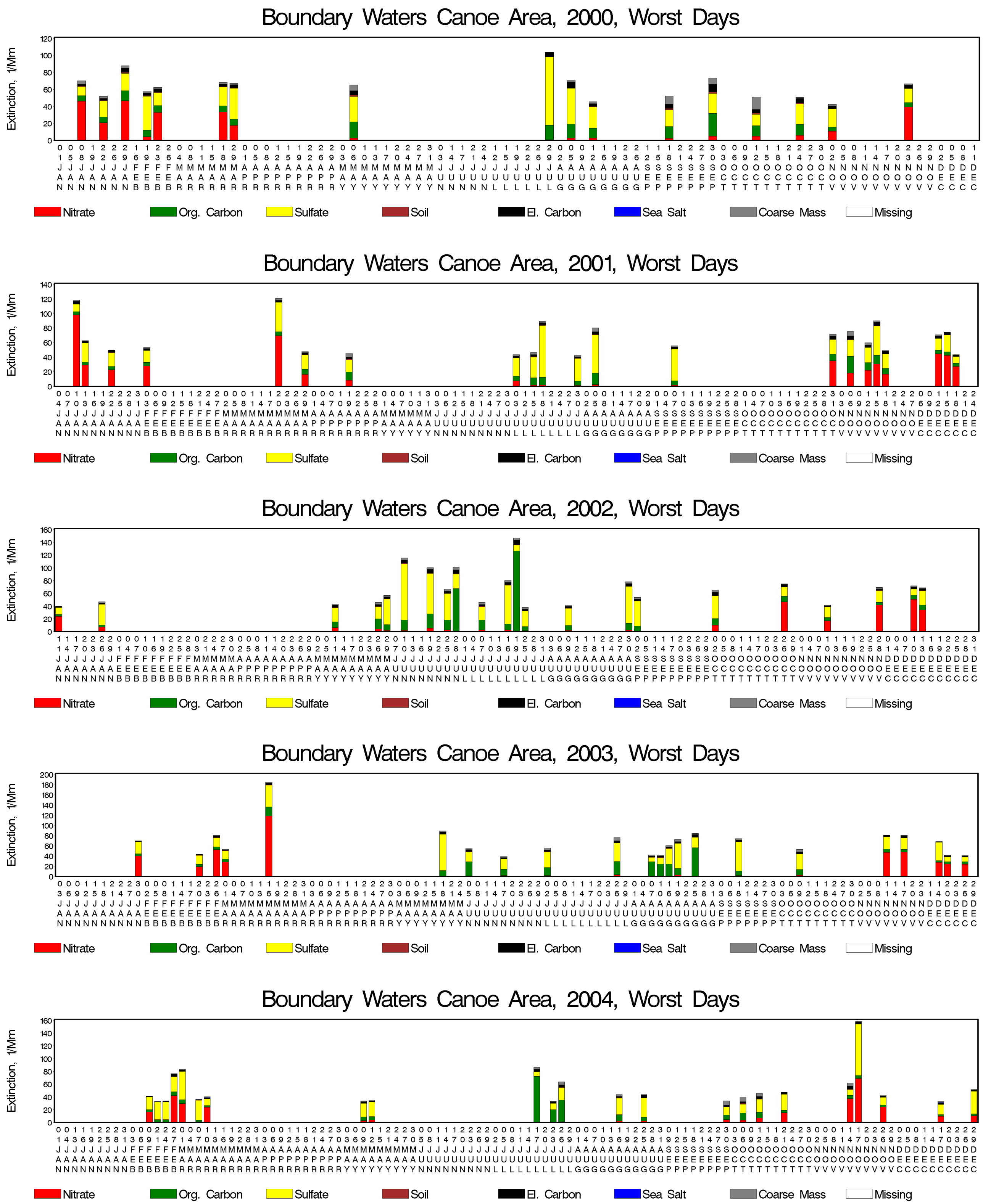

Figure 3. Daily light extinction values for 20% worst days at Boundary Waters (2000 – 2004)

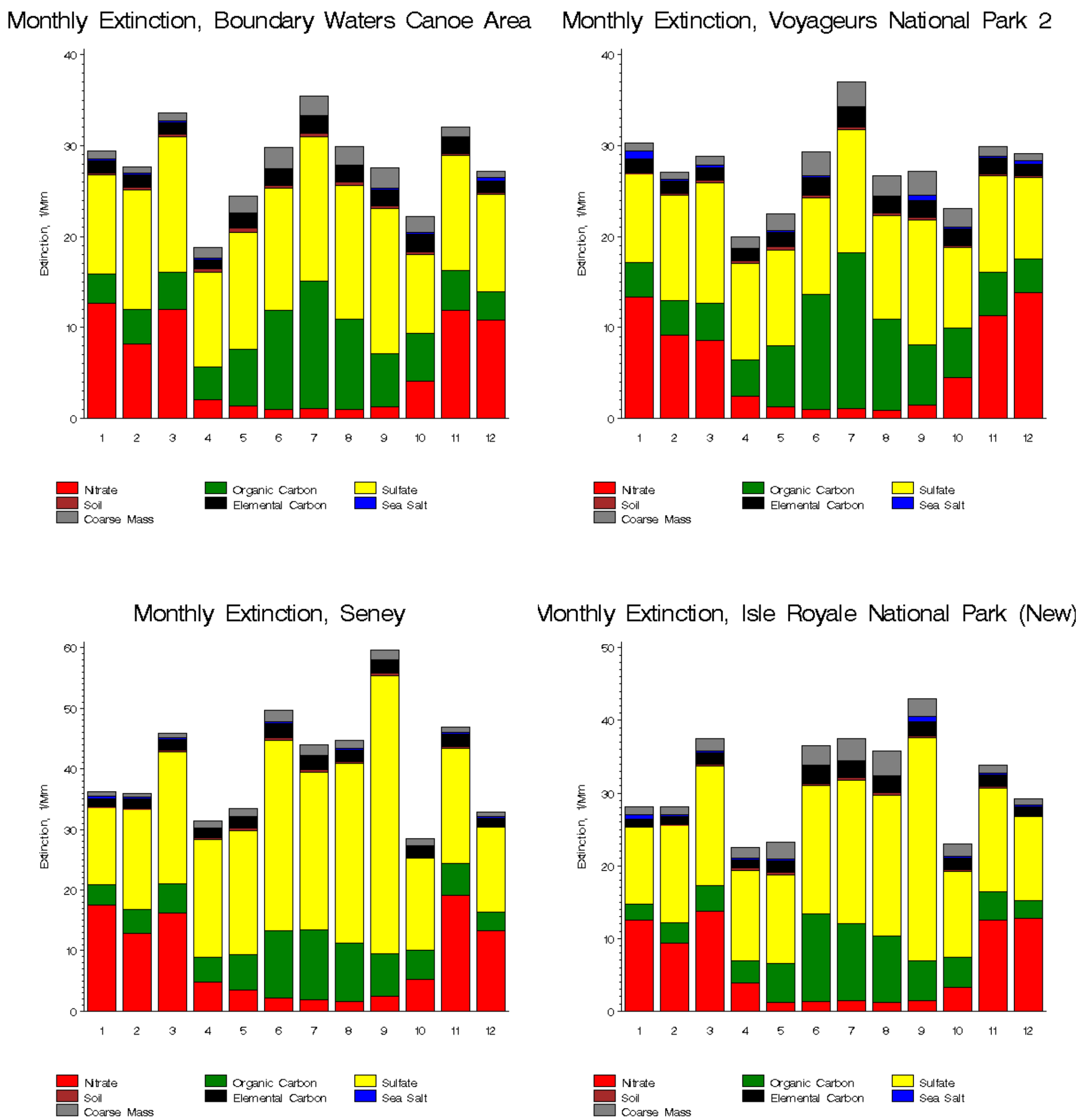

Figure 4. Monthly average light extinction values for northern Class I areas

2. Technical basis for visibility-related analyses

a. What are the present visibility conditions and how were the values calculated? How were the 20% worst and 20% best days determined?

Initially, the baseline (2000 – 2004) visibility condition values were derived using the average for the 20% worst and 20% best days for each year, as reported on the VIEWS website: http://vista.cira.colostate.edu/views/Web/IMPROVE/SummaryData.aspx . These values were calculated using the original IMPROVE equation for reconstructed light extinction.

Three changes were made to the baseline calculations to produce a new set of values. First, the reconstructed light extinction equation was revised by the IMPROVE Steering Committee in 2005 (DeBell, et al, 2006). The new IMPROVE equation was used to calculate updated baseline values.

Second, due to sampler problems, the 2002-2004 data for Boundary Waters were invalid for certain chemical species. (Note, sulfate and nitrate data at Boundary Waters were valid.) A "substituted" data set was developed by using values from Voyageurs for the invalid species.

Third, LADCO identified a number of days during 2000-2004 where data capture at the Class I monitors was incomplete (e.g., coarse mass and soil were missing species) (Kenski, 2007). The missing data cause the days to be excluded from the baseline calculations. However, the light extinction due to the remaining measured species is significant (i.e., above the 80th percentile). It makes sense to include these days in the baseline calculations, because they are largely dominated by anthropogenic sources. (Only one of these days is driven by high organic carbon, which might indicate non-anthropogenic aerosol from wildfires.) As seen in Table 1, inclusion of these days in the baseline calculation results in a small, but measurable, effect on the baseline values (i.e., values increase from 0.2 to 0.8 dv).

Table 1. Average of 20% Worst Days, With and Without Missing Data Days

	Average Worst Day DV, per RHR	Average Worst Day DV, with Missing Data Days	Difference
BOWA	19.59	19.86	0.27
ISLE	20.74	21.59	0.85
SENE	24.16	24.38	0.22
VOYA	19.27	19.48	0.21

A summary of the initial and updated baseline values for the Class I areas in northern Michigan and northern Minnesota are presented in Table 2. The updated baseline values reflect the most current, complete understanding of visibility impairing effects and, as such, will be used for SIP planning purposes.

b. What are natural conditions and how were the values calculated?

Initially, the values for the natural conditions goal for each Class I area were taken directly from USEPA guidance (USEPA, 2003). These values were calculated using the original IMPROVE equation. This equation was revised by the IMPROVE Steering Committee in 2005 (DeBell, et al, 2006), and the new IMPROVE equation was used to calculate updated natural conditions values. The updated values are reported on the VIEWS website (http://vista.cira.colostate.edu/views/).
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A summary of the initial and updated natural conditions values are presented in Table 2. The updated natural conditions values (based on the new IMPROVE equation) will be used for SIP purposes. The states must establish goals that provide for reasonable progress towards achieving natural conditions. The reasonable progress goals must provide for an improvement in visibility for the 20% worst days, and no degradation in visibility for the 20% best days.

Table 2. Summary of Visibility Metrics for Northern Class I Areas in Terms of Deciviews

Old IMPROVE Equation (Cite: VIEWS, November 2005)									
		20% Worst Days					**Baseline**	**2018**	**Natural**
		2000	**2001**	**2002**	**2003**	**2004**	**Value**	**URI Value**	**Conditions**
Voyageurs		18.50	18.00	19.00	19.20	17.60	18.46	16.74	11.09
BWCA		19.85	19.99	19.68	19.73	17.65	19.38	17.47	11.21
Isle Royale		20.00	22.00	20.80	19.50	19.10	20.28	18.17	11.22
Seney		22.60	24.90	24.00	23.80	22.60	23.58	20.73	11.37
		20% Best Days					**Baseline**		**Natural**
		2000	**2001**	**2002**	**2003**	**2004**	**Value**		**Conditions**
Voyageurs		6.30	6.20	6.70	7.00	5.40	6.32		3.41
BWCA		5.90	6.52	6.93	6.67	5.61	6.33		3.53
Isle Royale		5.70	6.40	6.40	6.30	5.30	6.02		3.54
Seney		5.80	6.10	7.30	7.50	5.80	6.50		3.69
New IMPROVE Equation (Cite: VIEWS, March 2006)									
		20% Worst Days					**Baseline**	**2018**	**Natural**
		2000	**2001**	**2002**	**2003**	**2004**	**Value**	**URI Value**	**Conditions**
Voyageurs		19.55	18.57	20.14	20.25	18.87	19.48	17.74	12.05
BWCA		20.20	20.04	20.76	20.13	18.18	19.86	17.94	11.61
Isle Royale		20.53	23.07	21.97	22.35	20.02	21.59	19.43	12.36
Seney		22.94	25.91	25.38	24.48	23.15	24.37	21.64	12.65
		20% Best Days					**Baseline**		**Natural**
		2000	**2001**	**2002**	**2003**	**2004**	**Value**		**Conditions**
Voyageurs		7.01	7.12	7.53	7.68	6.37	7.14		4.26
BWCA		6.00	6.92	7.00	6.45	5.77	6.43		3.42
Isle Royale		6.49	7.16	7.07	6.99	6.12	6.77		3.72
Seney		6.50	6.78	7.82	8.01	6.58	7.14		3.73

Notes: (1) BWCA values for 2002 - 2004 reflect "substituted" data.
(2) New IMPROVE equation values include Kenksi, 2007 adjustment for missing days

3. Evaluation of control measure effectiveness

   a. What tools are available to evaluate the effectiveness of emission reductions?

      USEPA's modeling guidelines (USEPA, 2007) recommend using air quality models, along with complementary analyses of ambient monitoring, emissions, and meteorological data to determine whether a given control strategy meets the air quality goal. CAMx was used by LADCO (LADCO, 2006; LADCO, 2007) and the Minnesota Pollution Control Agency (MPCA, 2008), while both CAMx and CMAQ were used by CENRAP (Environ, 2007).

      Figure 5 shows the spatial coverage of the modeling domains used by CENRAP, LADCO, and MPCA. CENRAP used the National Inter-RPO domain with 36 km grid spacing, LADCO used a subset of the National Inter-RPO domain (referred to as the "4rpos" domain) with 36 km spacing, and MPCA used the "4rpos" domain with 36 km spacing and a Minnesota domain with 12 km spacing. The purpose of the Minnesota 12 km domain was to address local source impacts on the northern Class I areas.

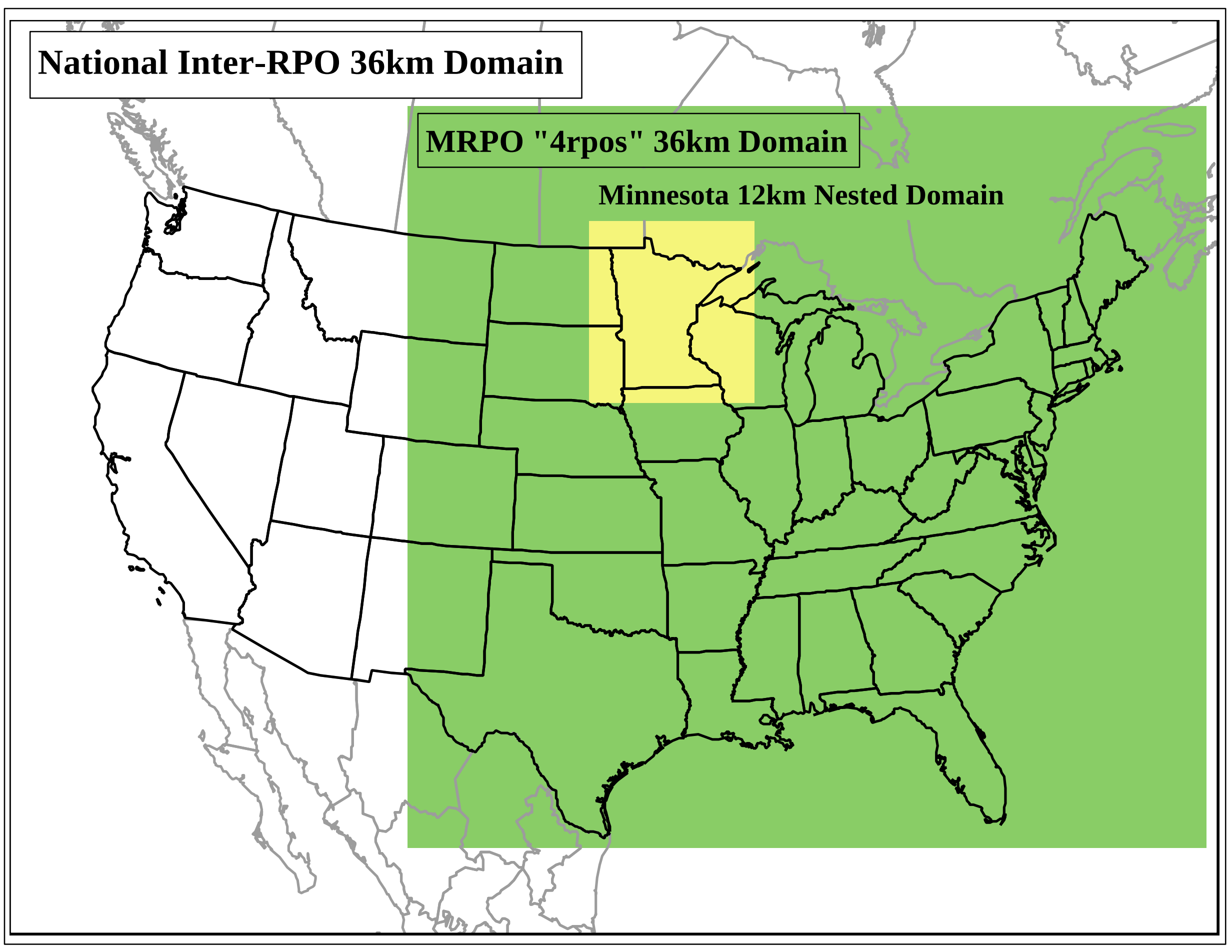


Figure 5. Modeling domains for CENRAP (National Inter-RPO 36km Domain), LADCO (MRPO "4rpos" 36km Domain), and MPCA (Minnesota 12km Nested Domain)

Two base years were used in the modeling: 2002 and 2005. USEPA's modeling guidelines recommend using 2002 as the baseline inventory year, but also allow for use of an alternative baseline inventory year, especially a more recent year (USEPA, 2007). LADCO initially conducted modeling with a 2002 base year (i.e., Base K4/Round 4 modeling). CENRAP and MPCA also used a 2002 base year in their modeling. The three sets of 2002 base year analyses are generally consistent, with differences attributable to modeling domain (i.e., CENRAP's domain is larger), baseline values (i.e., CENRAP's data do not reflect all the adjustments noted above), and emissions inventory data (e.g., different base year emission estimates, and growth and control factors). LADCO subsequently decided to conduct modeling with a 2005 base year (i.e., Base M/Round 5). Examination of multiple base years provides for a more complete technical assessment. The results from all four modeling analyses are discussed here.

The models were shown to provide reasonable estimates for sulfates and nitrates (see, for example, Figure 6), and can, therefore, be used to examine sulfate and nitrate control strategies. The models are less reliable for organic carbon – note, the large underestimation in monthly average organic carbon concentrations in the plots below. To compensate for model uncertainty and to provide a more robust analysis, additional information should be considered as part of a weight-of-evidence demonstration.

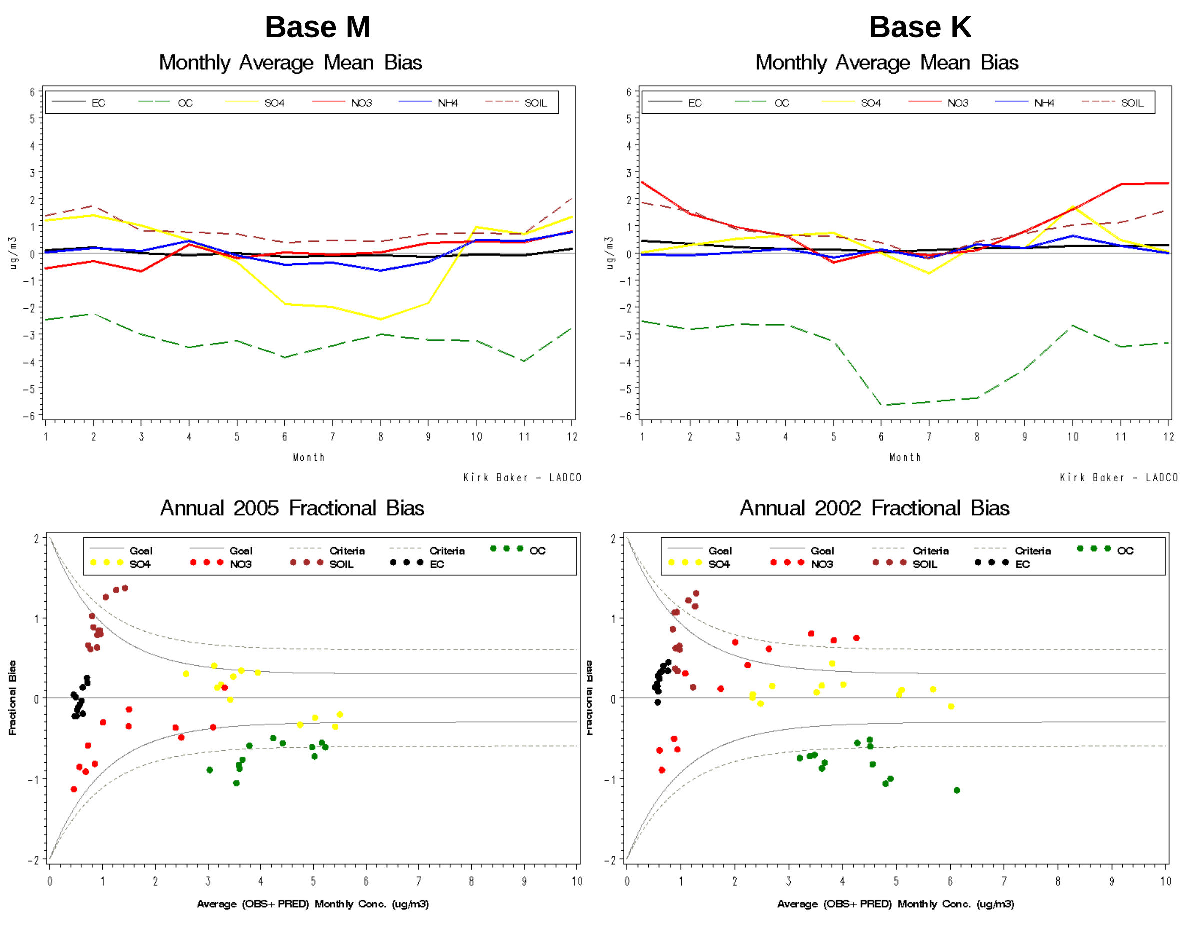


Figure 6. Results of LADCO's model performance for $PM_{2.5}$ – monthly average mean bias and annual fractional bias for Base M – 2005 base year (left side) and Base K – 2002 base year (right side)

b. How effective will existing (“on the books”) controls be in improving visibility in the northern Class I areas?

Air quality modeling conducted by LADCO, MPCA, and CENRAP assessed future year visibility levels based on the following existing (“on the books”) controls:

On-Highway Mobile Sources

- Federal Motor Vehicle Emission Control Program, low-sulfur gasoline and ultra-low sulfur diesel fuel
- Inspection/Maintenance programs (nonattainment areas)
- Reformulated gasoline (nonattainment areas)

Off-Highway Mobile Sources

- Federal control programs incorporated into NONROAD model (e.g., nonroad diesel rule), plus the evaporative Large Spark Ignition and Recreational Vehicle standards
- Heavy-duty diesel (2007) engine standard/Low sulfur fuel
- Federal railroad/locomotive standards
- Federal commercial marine vessel engine standards

Area Sources (Base M only)

- Consumer solvents
- AIM coatings
- Aerosol coatings
- Portable fuel containers

Power Plants

- Title IV (Phases I and II)
- NOx SIP Call
- Clean Air Interstate Rule
- Clean Air Mercury Rule

Other Point Sources

- MACT standards: VOC 2-, 4-, 7-, and 10-year MACT standards, combustion turbine, and industrial boiler/process heater/RICE MACT
- State NOx RACT rules (Illinois and Wisconsin)

The model results are provided in Table 3 and Figure 7. For the 20% worst days, “on the books” controls are expected to improve visibility levels, but will still result in levels above the uniform rate of visibility improvement line (i.e., glide path) in the Michigan and, perhaps, Minnesota Class I areas.

In comparing LADCO’s Round 4 and Round 5 results for the 20% worst days, one noticeable difference is that the Minnesota Class I areas are much closer to the glide path in the newer Round 5 modeling. This difference is due to more SO2 emission reduction in nearby states in the Round 5 modeling (i.e., -28% v. -41% - see Table 4), which reflects EPA’s latest (IPM3.0) EGU projections and, perhaps, differences in meteorology between 2002 and 2005.

For the 20% best days, “on the books” controls are expected to produce little change in visibility levels, but may result in a slight degradation in a few locations, including Seney. A preliminary review of source contributions and associated future year growth and control assumptions, however, suggests that these visibility levels may be overestimated (e.g., future year Canadian emissions do not reflect planned emission reductions).

Table 3. Modeling Results for Northern Class I Areas

Worst 20% Site		Model BY	**Baseline**	**2018 URI**	**2018 OTB**
BOWA1	CENRAP	2002	19.58	17.72	**18.30**
	MPCA	2002	19.9	17.9	**18.7**
	LADCO	2002	19.86	17.70	**18.94**
	LADCO	2005	19.86	17.94	17.94
VOYA2	CENRAP	2002	19.27	17.58	**18.37**
	MPCA	2002	19.9	17.8	**19.0**
	LADCO	2002	19.48	17.56	**19.18**
	LADCO	2005	19.48	17.74	17.63
SENE1	CENRAP	2002			
	MPCA	2002			
	LADCO	2002	24.38	21.35	**22.38**
	LADCO	2005	24.38	21.64	**22.59**
ISLE1	CENRAP	2002	20.74	18.78	**19.36**
	MPCA	2002			
	LADCO	2002	21.59	19.21	**20.04**
	LADCO	2005	21.59	19.43	**20.09**
ISLE9*	LADCO	2005	21.59	19.43	**19.84**
** = result for grid cell located on Isle Royale, all other results for grid cells with IMPROVE monitors*					

Best 20% Site		Model BY	**Baseline**		**2018 OTB**
BOWA1	CENRAP	2002	6.4		6.4
	MPCA	2002	6.4		**6.5**
	LADCO	2002	6.42		**6.87**
	LADCO	2005	6.42		6.14
VOYA2	CENRAP	2002	7.1		7.0
	MPCA	2002	7.1		7.1
	LADCO	2002	7.09		**7.34**
	LADCO	2005	7.09		6.75
SENE1	CENRAP	2002			
	MPCA	2002			
	LADCO	2002	7.14		**7.23**
	LADCO	2005	7.14		**7.71**
ISLE1	CENRAP	2002			
	MPCA	2002			
	LADCO	2002	6.75		6.47
	LADCO	2005	6.75		6.60
ISLE9*	LADCO	2005	6.75		6.52
** = result for grid cell located on Isle Royale, all other results for grid cells with IMPROVE monitors*					

Note: MPCA modeling for the Minnesota 12km domain looked at several receptors throughout the Class I areas. Results for Boundary Waters on the 20% worst days range from 18.3 – 19.0 dv, with an average value of 18.7 dv, which is consistent with the 36km results at the IMPROVE monitor location shown in the table.

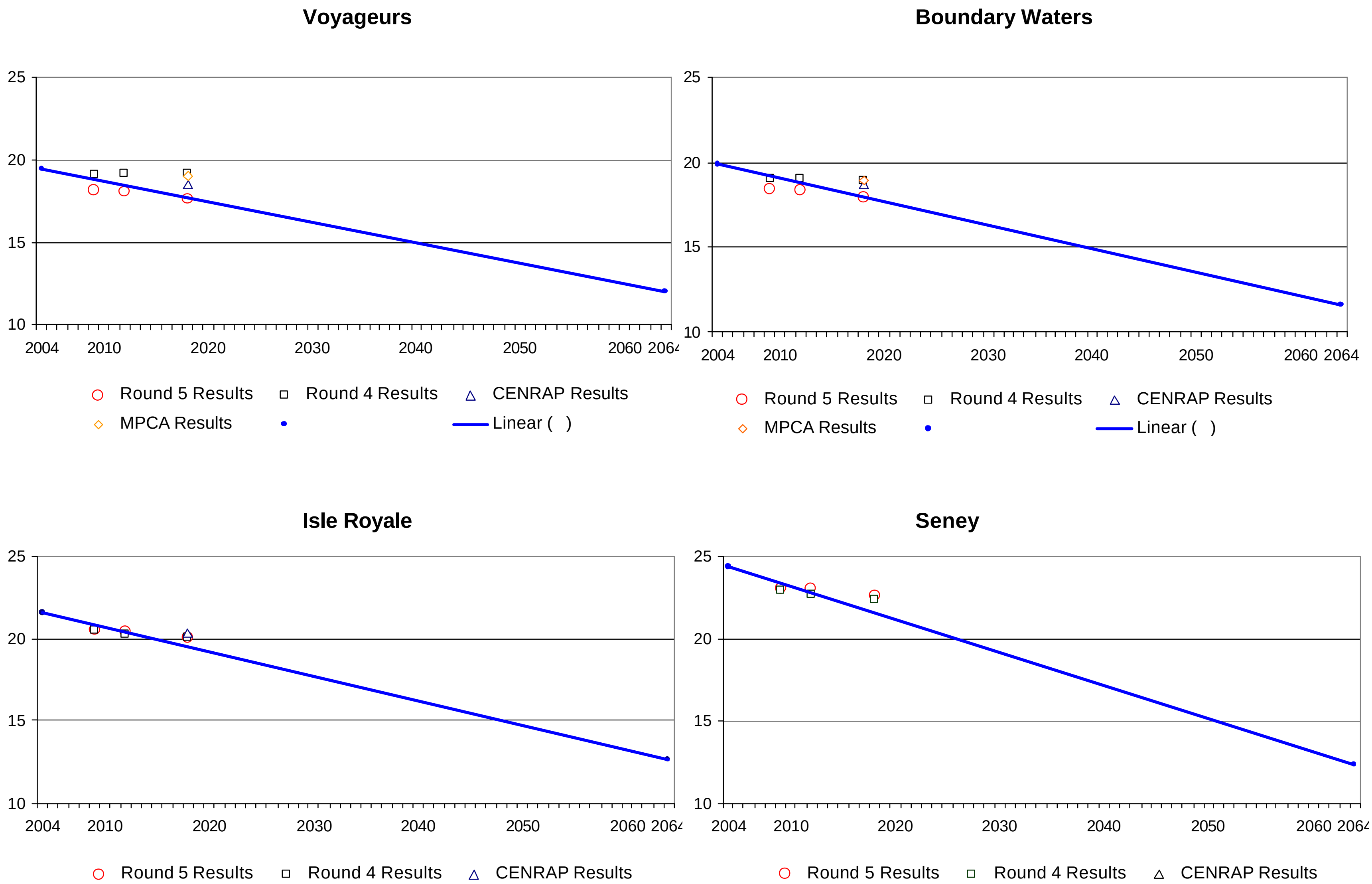


Figure 7. Modeling results for four northern Class I areas for 20% worst visibility days

Table 4. EGU SO2 Emissions for States in the Upper Midwest

	EGU - SO2 (Base K)			EGU - SO2 (Base M)	
State	**2002**	**2018**		**2005**	**2018**
Minnesota	318	266		319	188
		-16%			***-41%***
Wisconsin	602	500		545	435
		-17%			***-20%***
Michigan	1,102	1,058		1,251	725
		-4%			***-42%***
Iowa	412	482		430	352
		17%			***-18%***
North Dakota	376	330		369	124
		-12%			***-67%***
Illinois	1,310	810		1,158	870
		-38%			***-25%***
Indiana	2,499	1,048		2,614	1,036
		-58%			***-60%***
Missouri	835	909		889	759
		9%			***-15%***
	7,454	**5,403**		**7,575**	**4,487**
		-28%			***-41%***

c. What additional control measures will be effective in improving visibility in the northern Class I areas?

LADCO's air quality modeling (Round 4) examined several additional control measures, as summarized below.

Sulfate Control Strategies: Reductions in SO2 emissions will decrease sulfate concentrations. Because most the SO2 emissions in the upper Midwest are from EGUs, additional EGU SO2 control measures were examined. In particular, the following SO2 emission targets were modeled (MRPO, 2005):

	SO2 (lb/MMBTU)	NOx (lb/MMBTU)
EGU1	0.15	0.10
EGU2	0.10	0.07

The modeling shows that additional EGU control will improve visibility in the northern Class I areas (see Table 5). Increasing the spatial extent of this additional control produces greater visibility improvement (i.e., 12-state control program provides more benefit than 5-state control program).

Table 5. LADCO Round 4 Modeling Results for EGU Control Strategy

		2018	2018	2018	2018
20% Worst Days	**Baseline**	**URI**	**OTB**	**EGU2 (5 state region)**	**EGU2 (12 state region)**
BOWA1	19.86	17.70	18.94	18.40	17.72
VOYA2	19.48	17.56	19.18	18.94	18.38
SENE1	24.38	21.35	22.38	21.26	20.63
ISLE1	21.59	19.21	20.04	19.09	18.64

Nitrate Control Strategies: Reductions in NOx emissions will decrease nitrate concentrations. NOx emissions in the upper Midwest are from a variety of sources, principally, mobile sources (on-road and off-road) and stationary sources (EGUs and non-EGUs). The modeling for EGU1 and EGU2 reflects lower SO2 and NOx emission targets. No additional NOx-specific strategies were modeled by LADCO to address regional haze.

To determine whether additional SO2 and NOx control measures satisfy the requirement for reasonable progress, an assessment of the five factors was performed (ECR, 2007a). Specifically, ECR examined reductions in SO2 and NOx emissions from EGUs and industrial, commercial, and institutional (ICI) boilers; NOx emissions from mobile sources and reciprocating engines and turbines; and ammonia emissions from agricultural operations. The impacts of "on the books" controls were also examined to provide a frame of reference for assessing the impacts of the additional control measures.

The results of ECR's analysis of the reasonable progress factors are summarized below:

Factor 1 (Cost of Compliance): The average cost effectiveness values (in terms of $ per ton are provided in Table 6. For comparison, cost-effectiveness estimates previously provided for "on the books" controls include:

CAIR	SO2: $700 - $1,200, NOx: $1,400 – $2.600 ($/T)
BART	SO2: $300 - $963, NOx: $248 - $1,770
MACT	SO2: $1,500, NOx: $7,600

Most of the cost-effectiveness values for the additional controls are within the range of cost-effectiveness values for "on the books" controls.

Factor 2 (Time Necessary for Compliance): All of the control measures can be implemented by 2018. Thus, this factor can be easily addressed.

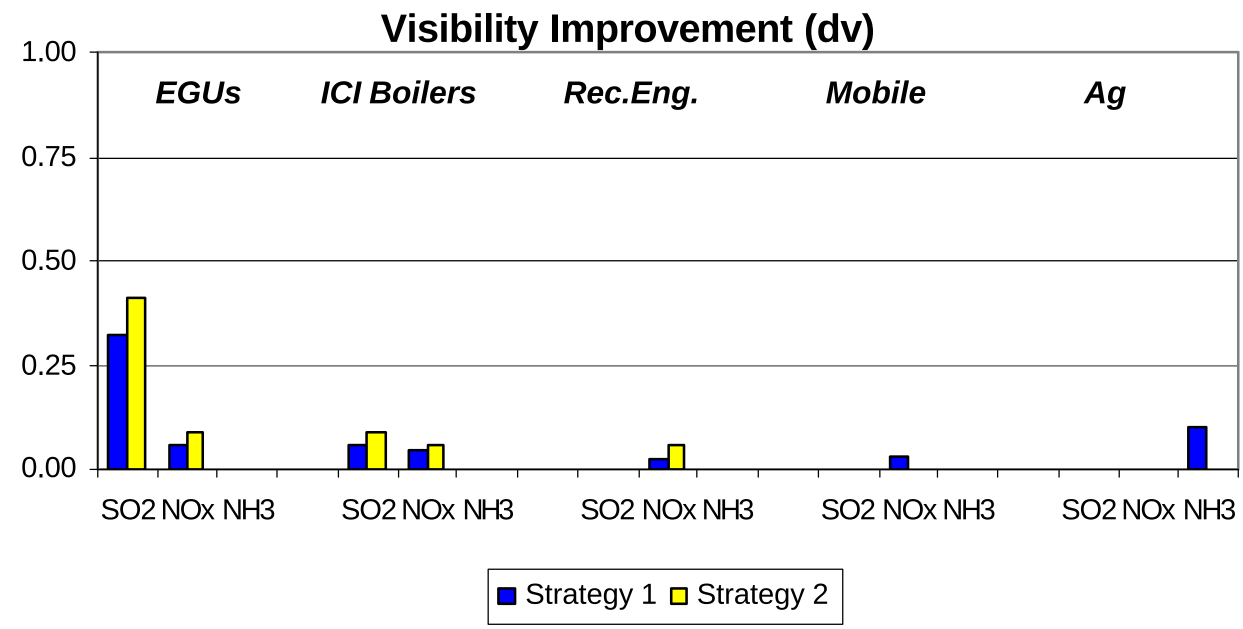
Factor 3 (Energy and Non-Air Quality Environmental Impacts): The energy and other environmental impacts are believed to be manageable. For example, the increased energy demand from add-on control equipment is less than 1% of the total electricity and steam production in the region, and solid waste disposal and wastewater treatment costs are less than 5% of the total operating costs of the pollution control equipment. It should also be noted that the SO2 and NOx controls would have beneficial environmental impacts (e.g., reduced acid deposition and nitrogen deposition).

Factor 4 (Remaining Useful Life): The additional control measures are intended to be market-based strategies applied over a broad geographic region. It is not expected that the control requirements will be applied to units that will be retired prior to the amortization period for the control equipment. Thus, this factor can be easily addressed.

Factor 5 (Visibility Impacts): The estimated incremental improvement in 2018 visibility levels for the additional measures is shown in Figure 8, along with the cost-effectiveness expressed in $M per deciview improvement). These results show that although EGU and ICI boiler controls have higher cost-per-deciview values (compared to some of the other measures), their visibility impacts are larger.

Table 6. Estimated Cost Effectiveness for Potential Control Measures

			Average Cost effectiveness ($/ton)		
Emission category	Control strategy	Region	SO2	NOX	NH3
EGU	EGU1	3-State	1,540	2,037	
		9-State	1,743	1,782	
	EGU2	3-State	1,775	3,016	
		9-State	1,952	2,984	
ICI boilers	ICI1	3-State	2,992	2,537	
		9-State	2,275	1,899	
	ICI Workgroup	3-State	2,731	3,814	
		9-State	2,743	2,311	
Reciprocating engines and turbines	Reciprocating engines emitting 100 tons/year or more	3-State		538	
		9-State		506	
	Turbines emitting 100 tons/year or more	3-State		754	
		9-State		754	
	Reciprocating engines emitting 10 tons/year or more	3-State		1,286	
		9-State		1,023	
	Turbines emitting 10 tons/year or more	3-State		800	
		9-State		819	
Agricultural sources	10% reduction	3-State			31 - 2,700
		9-State			31 - 2,700
	15% reduction	3-State			31 - 2,700
		9-State			31 - 2,700
Mobile sources	Low-NOX Reflash	3-State		241	
		9-State		241	
	MCDI	3-State		10,697	
		9-State		2,408	
	Anti-Idling	3-State		(430) - 1,700	
		9-State		(430) - 1,700	
	Cetane Additive Program	3-State		4,119	
		9-State		4,119	
Cement Plants	Process Modification	Michigan		-	
	Conversion to dry kiln	Michigan		9,848	
	LoTox™	Michigan		1,399	
Glass Manufacturing	LNB	Wisconsin		1,041	
	Oxy-firing	Wisconsin		2,833	
	Electric boost	Wisconsin		3,426	
	SCR	Wisconsin		1,054	
	SNCR	Wisconsin		1,094	
Lime Manufacturing	Mid-kiln firing	Wisconsin		688	
	LNB	Wisconsin		837	
	SNCR	Wisconsin		1,210	
	SCR	Wisconsin		5,037	
	FGD	Wisconsin		128 - 4,828	
Oil Refinery	LNB	Wisconsin		3,288	
	SNCR	Wisconsin		4,260	
	SCR	Wisconsin		17,997	
	LNB+FGR	Wisconsin		4,768	
	ULNB	Wisconsin		2,242	
	FGD	Wisconsin		1,078	



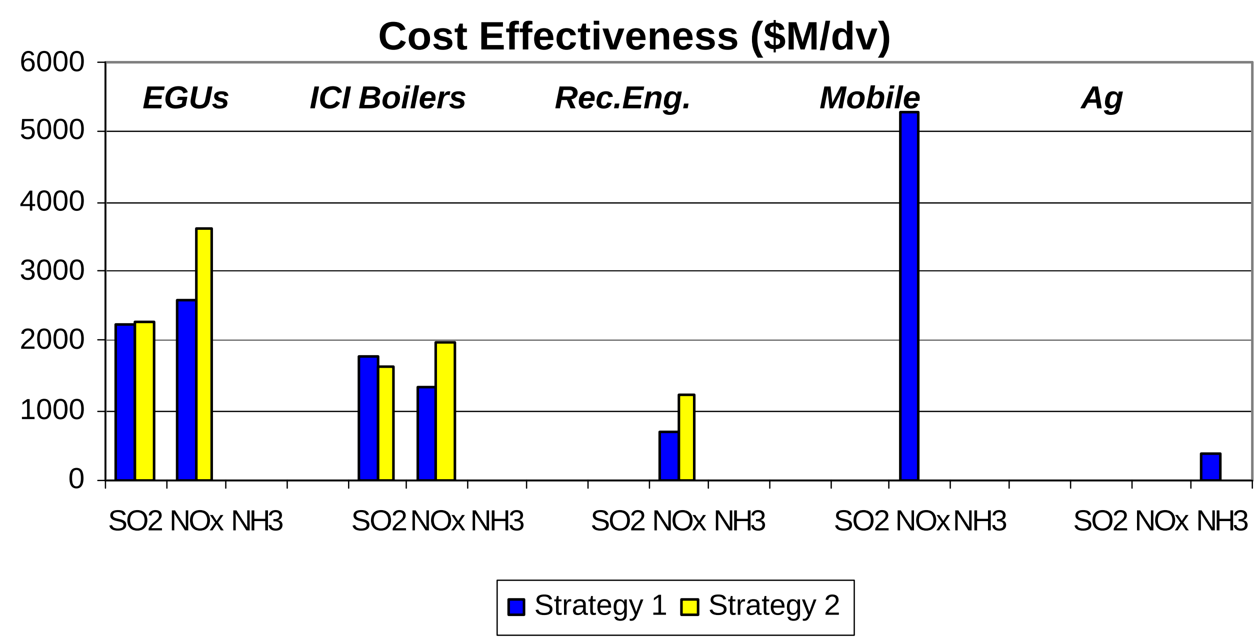


Figure 8. Results of ECR analysis of reasonable progress factors – visibility improvement (Factor 5) is on top, and cost effectiveness (Factor 1) is on bottom

Organic Carbon Strategies: Although organic carbon is also an important contributor to visibility impairment, no organic carbon control strategies were considered for the following reasons.

First, a special study was performed in Seney to identify sources of organic carbon (Sheesley, et al, 2004). As seen in Figure 9, the highest $PM_{2.5}$ concentrations occurred during the summer, with organic carbon being the dominant species. The higher summer organic carbon concentrations were attributed mostly to secondary organic aerosols of biogenic origin, because of the lack of primary emission markers in the summer[3], and concentrations of known biogenic-related species (e.g., pinonic acid) were also higher during the summer.

Second, to assess further whether fire activity is a significant contributor to visibility impairment in the northern Class I areas, the $PM_{2.5}$ chemical speciation data were examined for days with high organic and elemental carbon concentrations, which are indicative of biomass burning impacts. A handful of such days were identified:

Table 7. Days with High OC/EC Concentrations in Northern Class I Areas

Site	2000	2001	2002	2003	2004
Voyageurs	---	---	Jun 1	Aug 25	Jul 17
			Jun 28		
			Jul 19		
Boundary Waters	---	---	Jun 28	Aug 25	Jul 17
			Jul 19		
Isle Royale	---	---	Jun 1	Aug 25	---
			Jun 28		
Seney	---	---	Jun 28	---	---

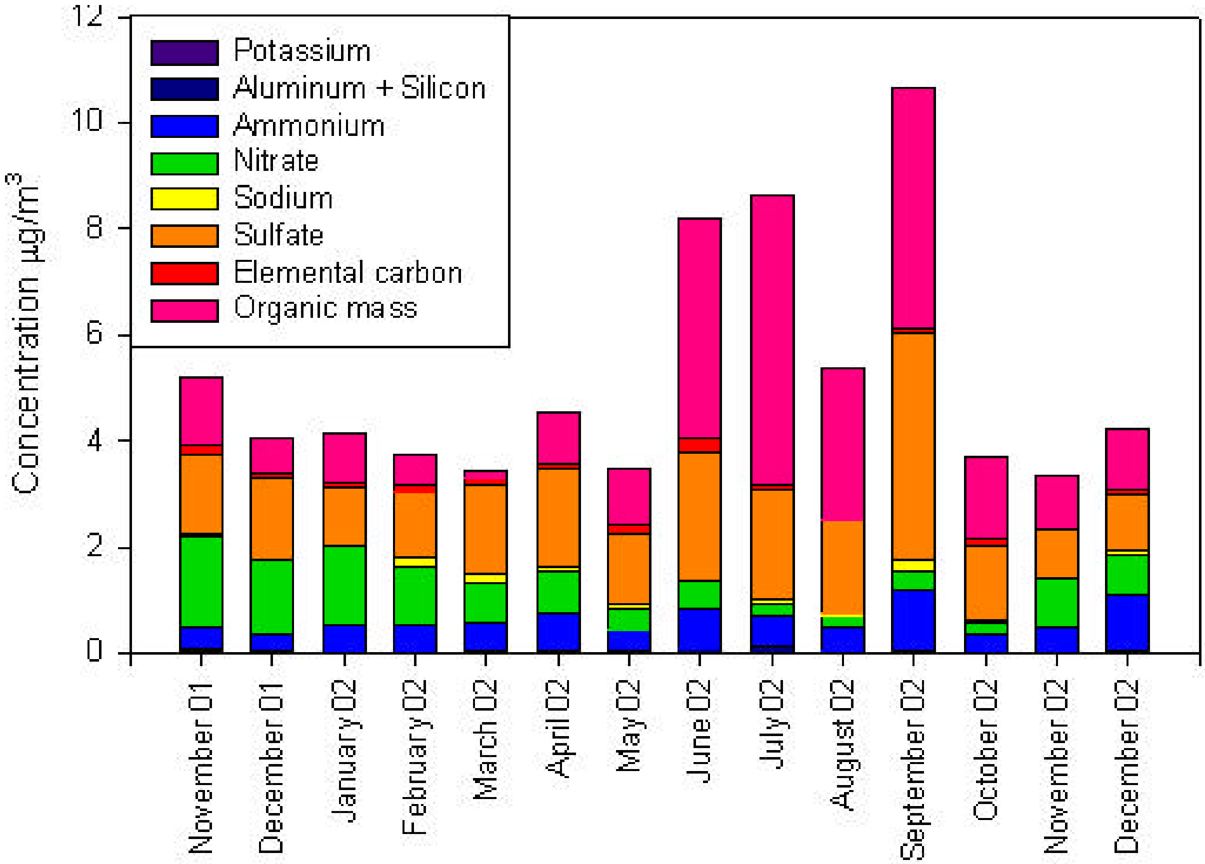
Back trajectories on these days point mostly to wildfires in Canada. Elimination of these high organic carbon concentration days has a small effect in lowering the baseline visibility levels in the northern Class I areas (i.e., Minnesota Class I areas change by about 0.3 deciviews, and Michigan Class I areas change by less than 0.2 deciviews).

This suggests that fire activity, although significant on a few days, is on average a relatively small contributor to visibility impairment in the northern Class I areas.

In summary, these two analyses indicate that organic carbon in the northern Class I areas is largely uncontrollable.

Finally, the modeling results are presented in Figure 10 in terms of chemical species. In comparison to the 2000-2004 baseline and 2018 projected visibility level, the 2064 natural conditions level reflects comparable organic carbon concentrations, but much lower sulfate and nitrate concentrations. This suggests the need for additional sulfate and nitrate concentration reduction to achieve natural conditions.

[3] Analysis of primary source emission markers and chemical mass balance modeling of the Seney data showed that the impact of primary emission sources (e.g., biomass burning, motor vehicles, and road dust) was fairly low. Biomass burning, in particular, contributed less than 1% on an annual average basis, although episodic impacts were found (e.g., see high organic carbon days in Figure 3).



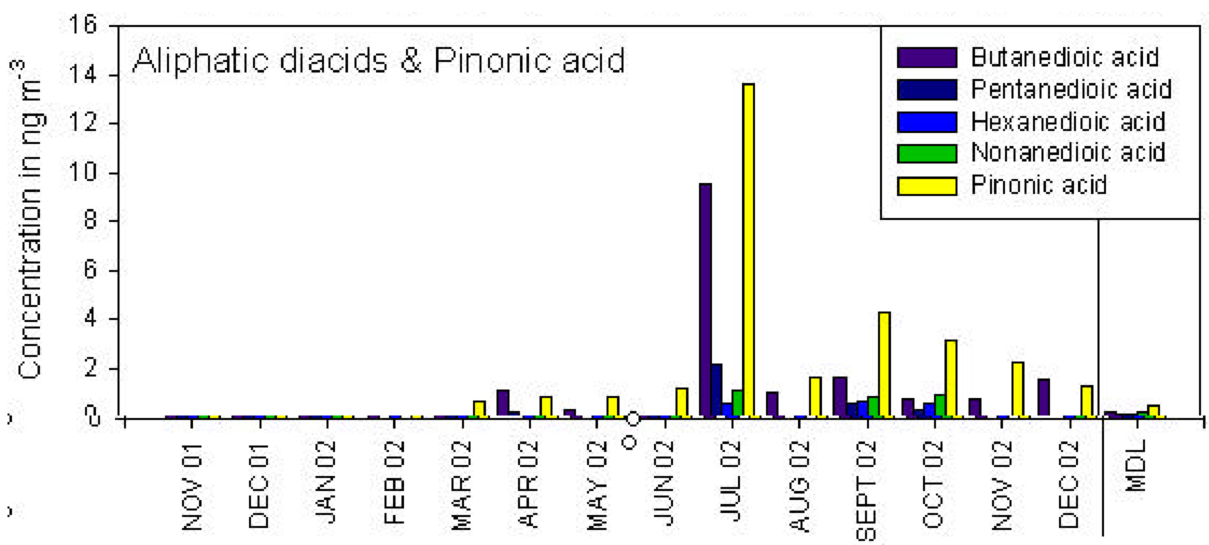


Figure 9. Monthly concentrations of $PM_{2.5}$ species (top) and biogenic-related organic carbon species in Seney (bottom)

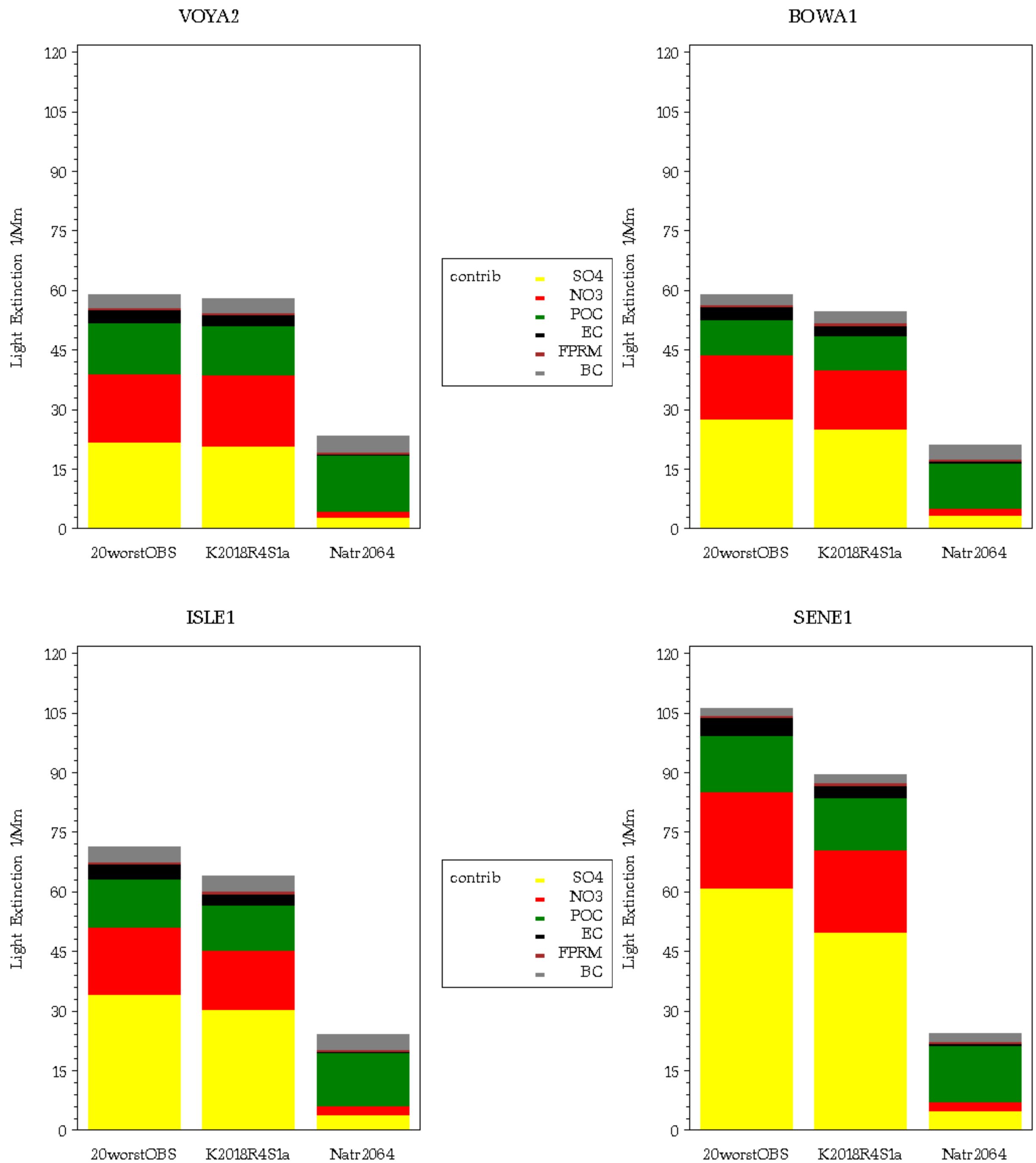


Figure 10. Comparison of 2002 base yea, 2018 future year, and 2064 natural condition levels for the four northern Class I areas (LADCO Round 4 modeling)

d. Should we consider control measures for ammonia?

Technical analyses have shown that $PM_{2.5}$ concentrations will respond to reductions in sulfate, nitrate (nitric acid), and ammonia – see, for example, Figure 11 based on data from the Great River Bluffs, MN site in the Midwest regional ammonia network (Blanchard, 2005). The plot shows $PM_{2.5}$ concentrations as a function of ammonia (NH3) and nitric acid (HNO3). Reductions in ammonia (i.e., movement to left of the baseline value (represented by the red star), as well as reductions in nitric acid (i.e., movement downward from the baseline value) result in lower $PM_{2.5}$ concentrations. Thus, ammonia emission reductions will lower $PM_{2.5}$ concentrations and improve visibility levels in the northern Class I areas.

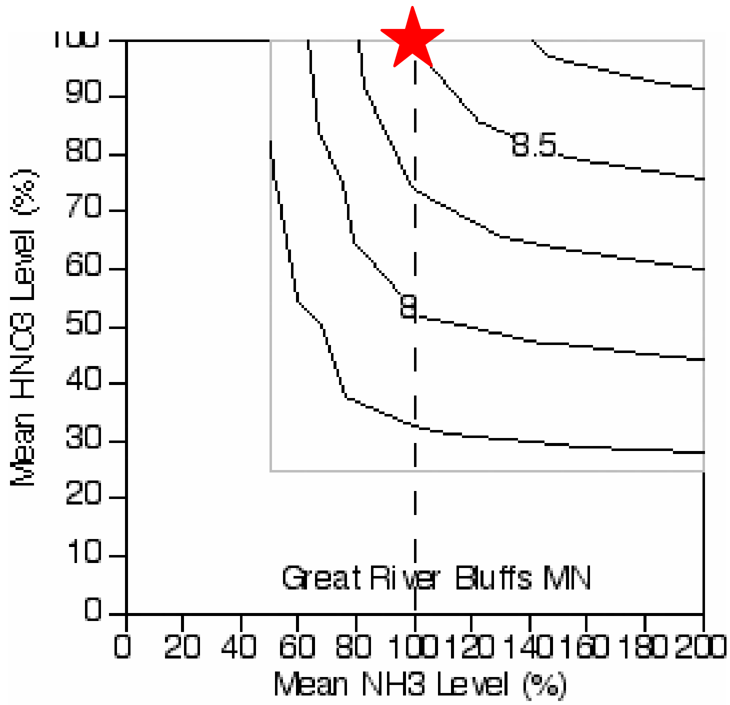


Figure 11. Predicted $PM_{2.5}$ mass levels at Great River Bluffs, MN as functions of changes in ammonia and nitric acid

Current regional inventories show most ammonia emissions come from livestock waste and fertilizer applications. A white paper on candidate control measures for agricultural ammonia emissions was prepared by a contractor (ECR, 2007b). ECR examined several measures which would mitigate air emissions, and water pollution from livestock waste management and synthetic fertilizer usage. Information on emission reductions (and other impacts), cost effectiveness, and geographic and seasonal applicability are considered in the white paper.

Further analyses (and discussions with stakeholders) are necessary before deciding whether to pursue control measures for ammonia. Key issues which need to be addressed include technical uncertainties, such as reliability of emission estimates, treatment of ammonia by current photochemical modeling systems, and lack of ambient measurements. It is worth noting, however, that LADCO and CENRAP have attempted to address these uncertainties by supporting development of a new process-based emissions model, conducting model sensitivity studies of ammonia deposition, and collecting ambient ammonia data as part of the Midwest regional ammonia network. Another issue was noted by USEPA in its final CAIR rulemaking: “reductions in ammonia emissions alone would also tend to increase the acidity of $PM_{2.5}$ and precipitation…. this might have untoward environmental or health consequences.” (70 FR 25182)

Section 3
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Web Sites:
http://vista.cira.colostate.edu/views/

APPENDIX I

Contribution Assessment for Northern Class I Areas

Air quality data analyses involving back trajectories, dispersion modeling, and emissions inventories were examined to provide information on source region and source sector contributions to regional haze in the northern Class I areas. Based on this information, the following key findings should be noted:

- The most important contributing states are Michigan, Minnesota, and Wisconsin, as well as Illinois, Indiana, Iowa, Missouri, and North Dakota.

- The most important contributing pollutants and source sectors are SO2 emissions from electrical generating units (EGUs), which lead to sulfate formation, and NOx emissions from a variety of source types (e.g., motor vehicles), which lead to nitrate formation. Ammonia emissions from livestock waste and fertilizer applications are also important, especially for nitrate formation.

LADCO Back Trajectory Analysis (1997-2001 Data)

Back trajectories were prepared by LADCO using data for 1997-2001 (all sampling days), a start height of 200 m, and a 72-hour (3-day) trajectory period (Kenski, 2004). By combining trajectory frequencies with concentration information, the average contribution to $PM_{2.5}$ mass and individual $PM_{2.5}$ species was estimated (which, in turn, was used to estimate the average contribution to light extinction). The results for three northern Class I areas are provided in Table I-1 for the 20% best days, all days, and 20% worst days. The table shows that the most important contributing states are Michigan, Minnesota, and Wisconsin, and, to a lesser degree North Dakota, South Dakota, Missouri, Iowa, Illinois, Ontario, and Manitoba.

LADCO Back Trajectory Analysis (2000-2003 Data)

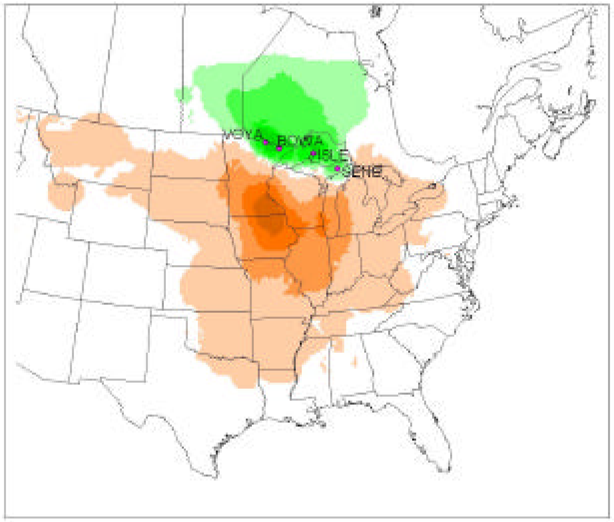
Back trajectories were prepared by LADCO using data for 2000-2003 (20% worst and 20% best days), a start height of 200m[4], and a 120-hour (5-day) trajectory period (Kenski, 2005). Composite back trajectory plots were prepared for light extinction, sulfate, and nitrate (see Figure I-1). For the high light extinction (poor visibility) and high sulfate and nitrate concentration days, the orange areas are where the air is most likely to come from, and the green areas are where the air is least likely to come from. As can be seen, bad air days are generally associated with transport from Michigan, Minnesota, and Wisconsin, as well as North Dakota, South Dakota, Missouri, Iowa, Illinois, and Indiana. On the other hand, the good air days (low extinction) are generally associated with transport from Canada.

[4] A sensitivity analysis was performed to determine the effect of start height. Increasing westerly influence was seen as start height increases. 200 m was assumed to be an appropriate compromise to represent the mixed boundary layer, but not unduly influenced by surface features.

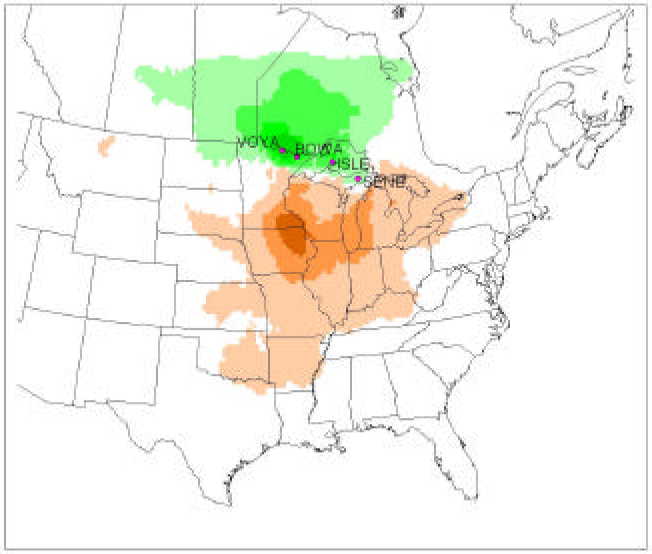
Table I-1. Estimated Contributions to Visibility (Light Extinction) – Percentages

		Boundary Waters Extinction			Voyageurs Extinction			Seney Extinction		
		Best	All Days	Worst	Best	All Days	Worst	Best	All Days	Worst
US	Alabama		0.03						0.20	0.39
	Arkansas		0.30	0.40		0.10	0.19		1.54	2.93
	Florida								0.09	0.17
	Georgia								0.21	0.39
	Illinois		1.68	2.74		0.50	1.22		4.99	7.43
	Indiana		0.57	1.18					1.67	2.17
	Iowa		5.14	7.44		6.12	10.24		5.27	5.66
	Kentucky								1.14	2.18
	Louisiana		0.12	0.23		0.03	0.06		0.78	1.23
	Michigan	0.78	1.17	0.66	0.27	1.22	1.57	14.51	13.68	14.68
	Minnesota	22.04	34.75	37.63	20.96	34.60	36.88	1.46	5.41	3.79
	Mississippi		0.06						0.62	1.04
	Missouri		2.17	3.26		1.02	0.30		2.42	3.17
	New Hampshire								0.02	
	New York								0.07	0.10
	North Carolina		0.09						0.19	0.36
	North Dakota	1.21	5.13	5.91	1.59	6.51	7.11		1.26	0.64
	Ohio		0.19	0.23				0.07	1.61	2.80
	Pennsylvania							0.49	0.15	0.26
	South Carolina								0.21	0.39
	South Dakota	0.45	3.06	4.38		4.08	6.93		1.13	1.12
	Tennessee		0.01						0.47	0.85
	Vermont								0.02	
	Virginia		0.03						0.17	0.33
	West Virginia		0.05						0.54	1.02
	Wisconsin	1.31	7.86	10.06		5.50	9.66	0.26	10.63	8.44
	Western States	1.10	4.31	5.74		7.05	9.53		5.80	5.90
Canada	Manitoba	9.95	7.45	3.71	17.65	10.35	6.04	3.77	2.37	0.77
	Ontario	47.52	15.96	8.92	49.56	13.59	4.98	50.97	12.86	7.66
	Quebec	1.77	0.15		0.21	0.01		0.97	0.93	0.41
	Other Provinces	2.27	3.73	2.46	6.05	6.29	2.35	0.86	1.72	2.28
Other (over water, etc.)		11.61	6.02	5.05	3.72	3.05	2.94	26.65	21.86	21.44
Total		100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

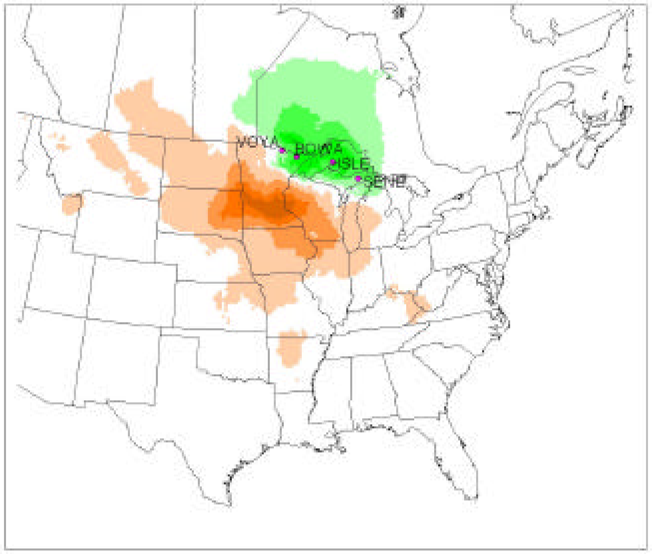
Note: Because Seney is more surrounded by water (the Great Lakes) than the other monitoring sites, the analysis shows greater impacts associated with the Other (over water) category. Actually, most of the Other (over water) impacts at Seney are from nearby (over land) emission sources, not over water emission sources.



High extinction days



High sulfate concentration days



High nitrate concentration days

Figure I-1. Composite back trajectories for light extinction, sulfates, and nitrates

Note: orange is where air is most likely to come from, green is where air is least likely to come from

LADCO Back Trajectory Analysis (2000 – 2005 Data)
LADCO's back trajectory study (based on 2000-2003 data) was updated using data for 2000-2005 (Kenski, 2007). Composite back trajectory plots were prepared for each Class I area (see Figures I-2 and I-3). In each plot, the orange areas are where the air is most likely to come from, and the green areas are where the air is least likely to come from. As can be seen, bad air days are generally associated with transport from Michigan, Minnesota, and Wisconsin, as well as North Dakota, South Dakota, Missouri, Iowa, Illinois, and Indiana. On the other hand, the good air days are generally associated with transport from Canada.

Figures I-4 and I-5 compare the transport patterns for the two base years: 2002 and 2005. Figure I-4 shows strong similarities in the transport patterns for the two years. Additional detail on the transport patterns for the two base years is provided in Figure I-5 for Seney and Voyageurs. The dots are plotted in graduated colors, by day, so that it is easier to distinguish one day from another. It is worth noting that even though a few of the worst-day trajectories originate in Canada, many of these trajectories actually spend significant time in the U.S. and should not be thought of as strictly Canadian influences.

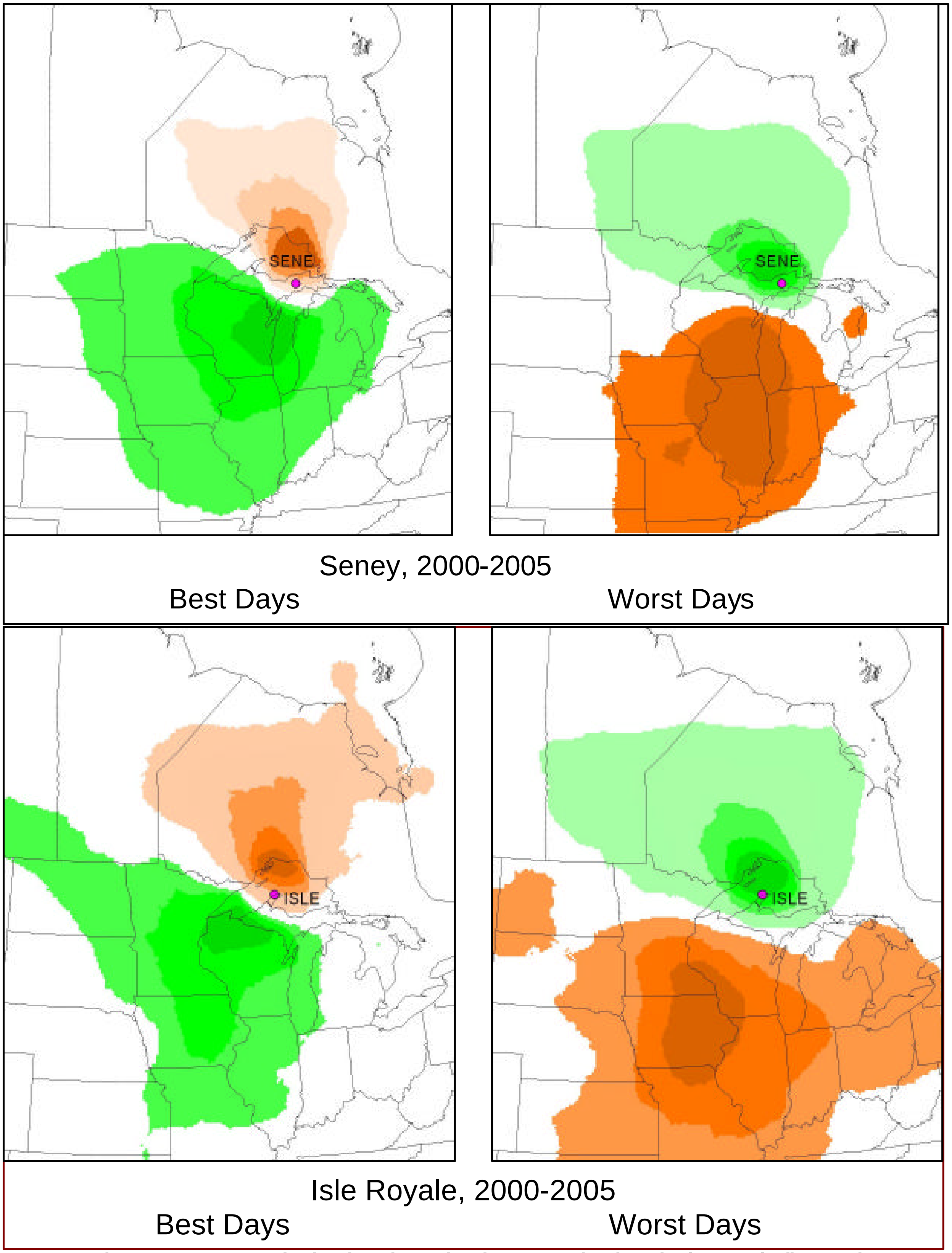


Figure I-2. Composite back trajectories for Seney (top) and Isle Royale (bottom)

Note: orange is where air is most likely to come from, green is where air is least likely to come from

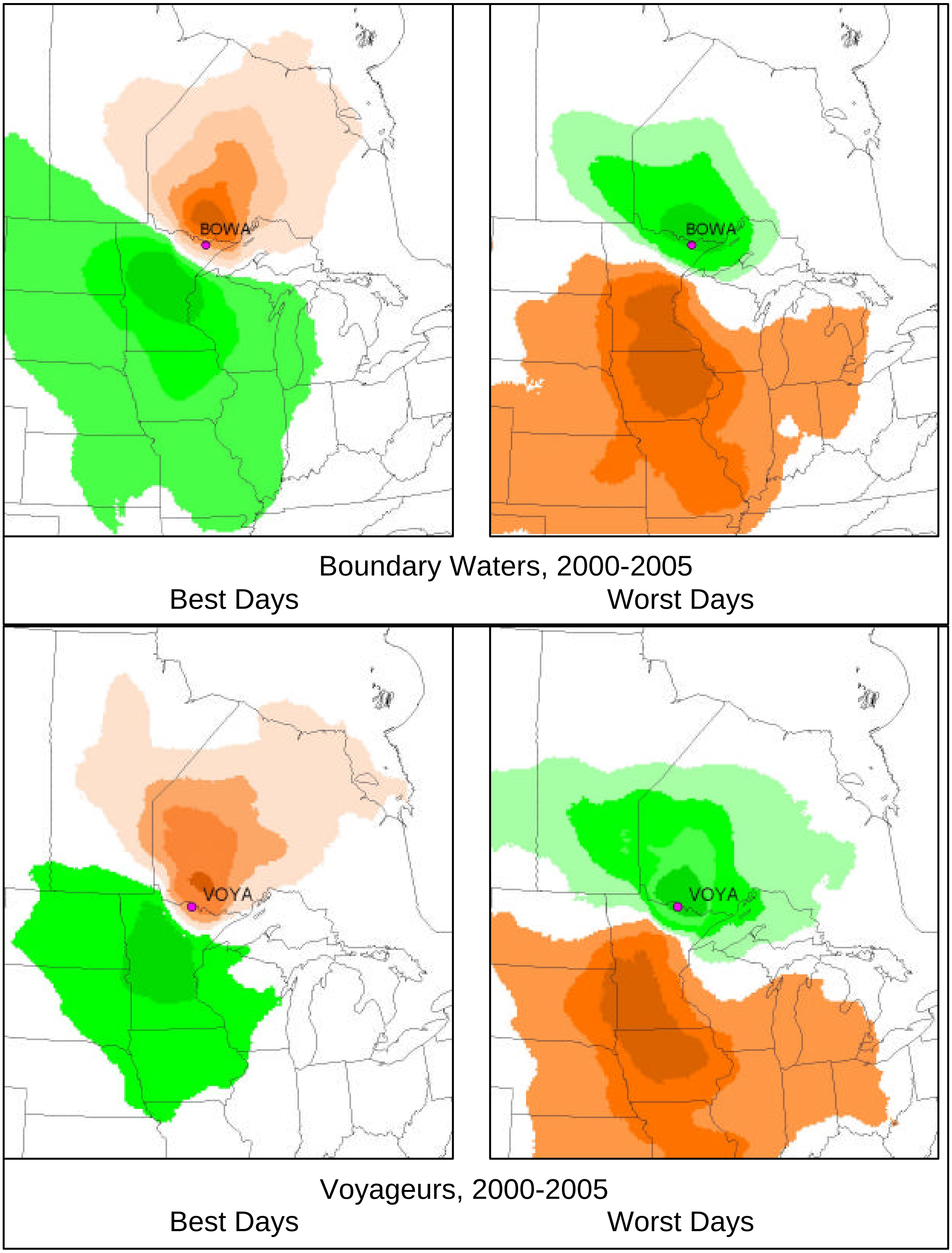


Figure I-3. Composite back trajectories for Boundary Waters (top) and Voyageurs (bottom)
Note: orange is where air is most likely to come from, green is where air is least likely to come from

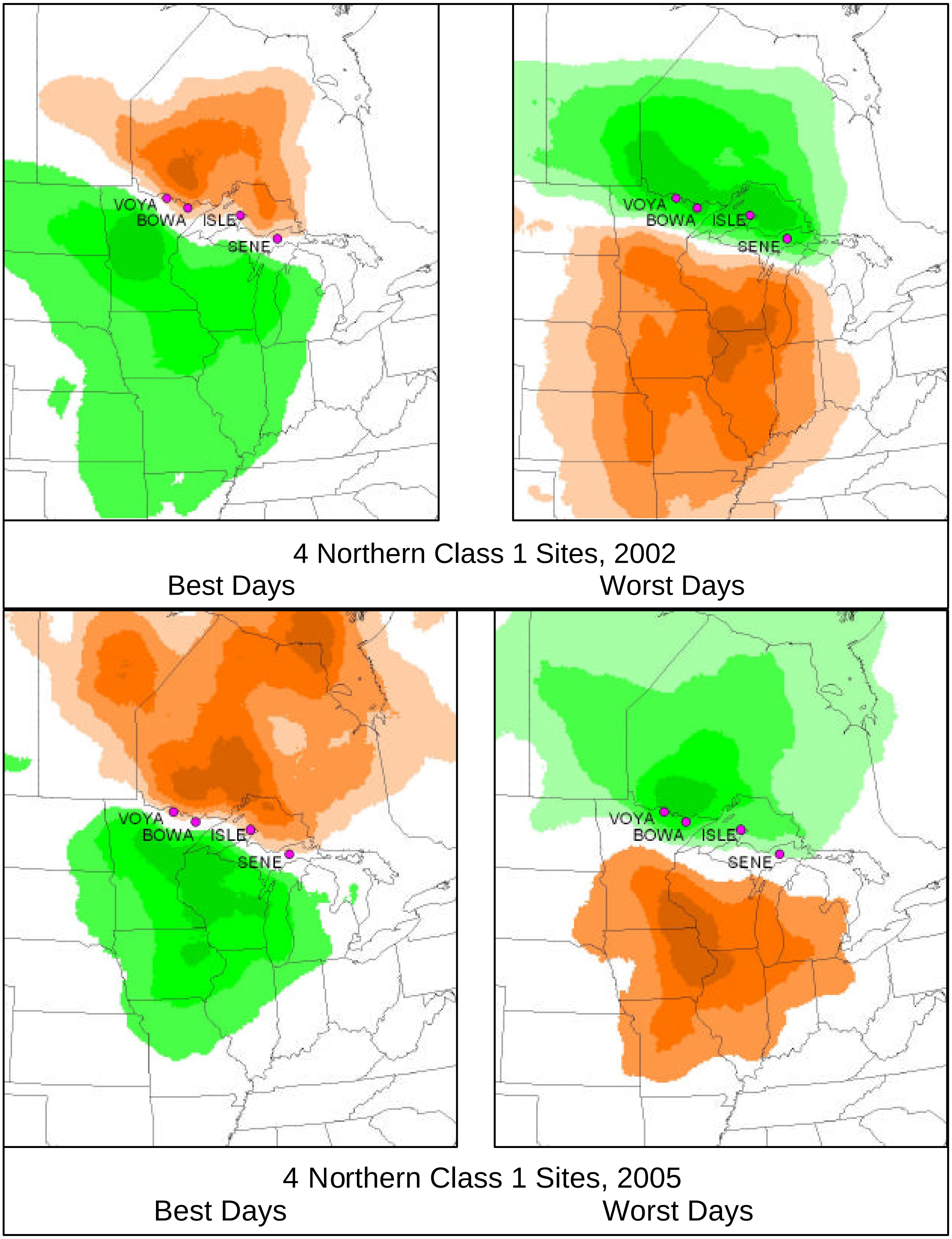


Figure I-4. Composite back trajectories for 2002 (top) and 2005 (bottom)
Note: orange is where air is most likely to come from, green is where air is least likely to come from

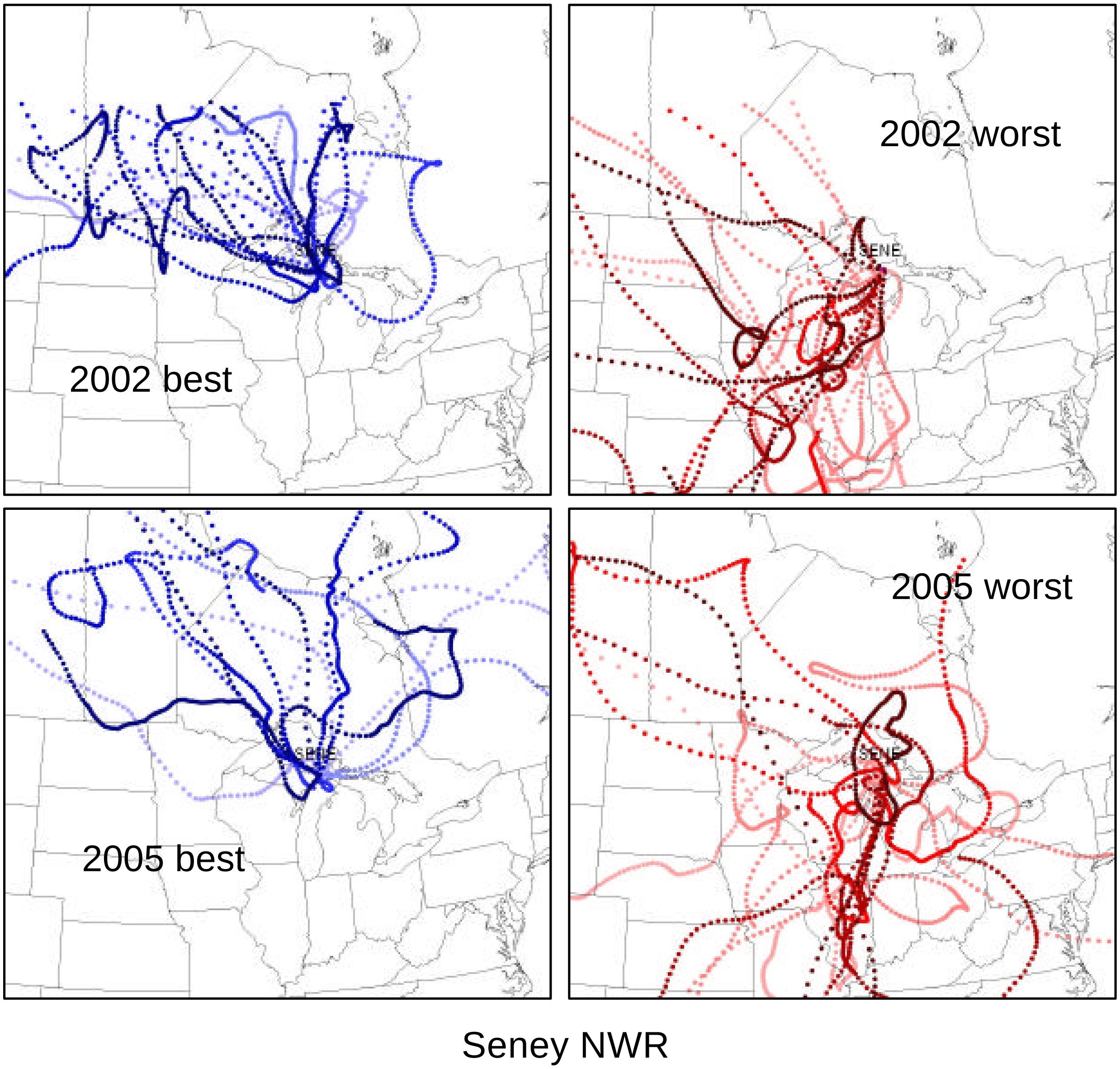


Figure I-5a. Composite back trajectories for Seney

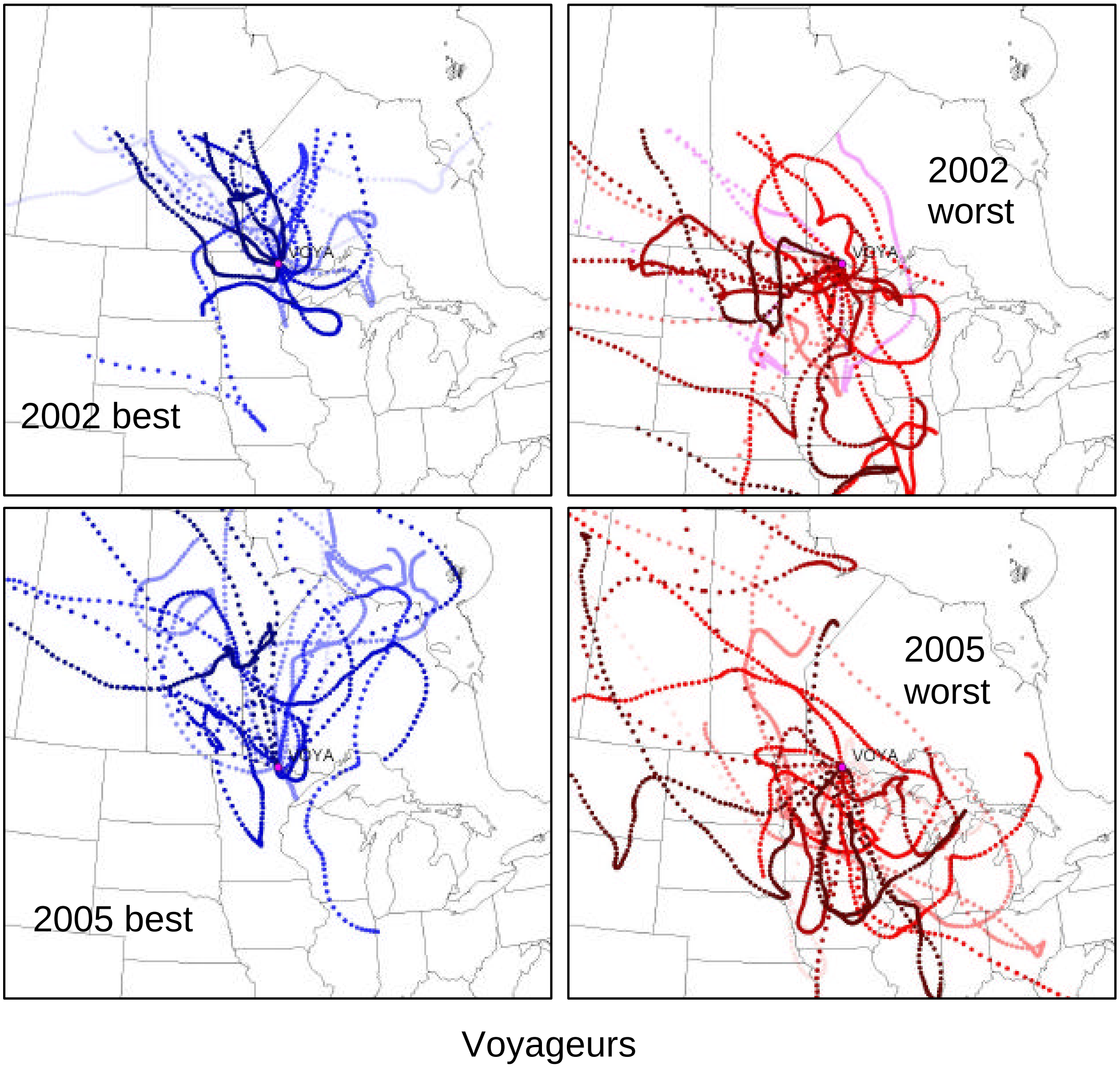


Figure I-5b. Composite back trajectories for Voyageurs

CENRAP Areas of Influence Assessment Using Back Trajectories and Other Tools

Areas of Influence (AOI) were developed using several back trajectory analyses, including Residence Time Difference Plots, the Probability of Regional Source Contribution to Haze plots, and Tagged Species Source Apportionment Results (Alpine Geophysics, 2006). AOIs were constructed for 10 Class I areas in the CENRAP region, including Boundary Waters/Voyageurs (see Figure I-6). Green contours represent AOIs for nitrates, and red contours represent AOIs for sulfates. Similar to LADCO's composite trajectory plots in Figure I-1, nitrate impacts are associated with more westerly transport, while sulfate impacts are associated with more southerly transport.

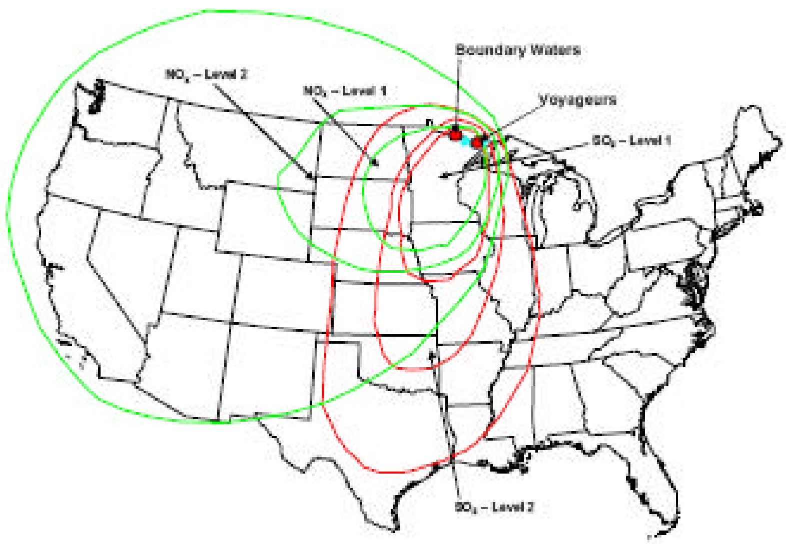


Figure I-6. AOIs for nitrates (green) and sulfates (right) for Boundary Waters/Voyageurs

CENRAP Emissions Inventory Potential Analysis

Back trajectories were combined with emissions inventory data to estimate the Emissions Impact Potential (CENRAP, 2006). This approach weights emissions at a particular location by the probability of transport from that location to a given receptor under days of high sulfate or nitrate concentrations. The EIP results for SO2 and NOx for Voyageurs, which are provided in Figure I-7, show that contributions are greatest from source regions in northeastern Minnesota and the Twin Cities urban area.

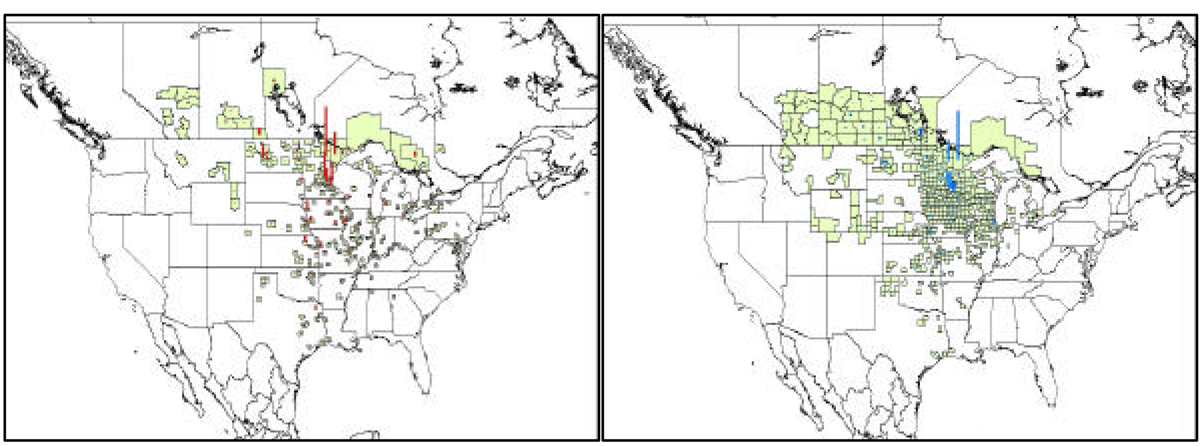


Figure I-7. EIP for SO2 (left) and NOx (right) as calculated for Voyageurs

Receptor Modeling Study
Ambient monitoring data for the period 1991 – 2002 were analyzed to identify sources impacting $PM_{2.5}$ levels in several Class I areas, including Boundary Waters (DRI, 2005). Using statistical tools (i.e., receptor models), the relative contributions associated with various primary and secondary emissions were estimated. The results from three receptor models (CMB, PMF, and UNMIX) for Boundary Waters are presented in Figure I-8. Because most of the fine particle mass is secondary in nature, the tools were unable to provide much definition - e.g., over 80% of the impacts on the 20% worst visibility days at Boundary Waters was due to a combination of secondary sulfate, secondary nitrate, and (mostly secondary) organic carbon. Back trajectory analysis of these sources showed the largest impacts are associated with transport from the following directions: (1) sulfate – south and southeast, (2) nitrate – west and southwest, and (3) organics – west and south.

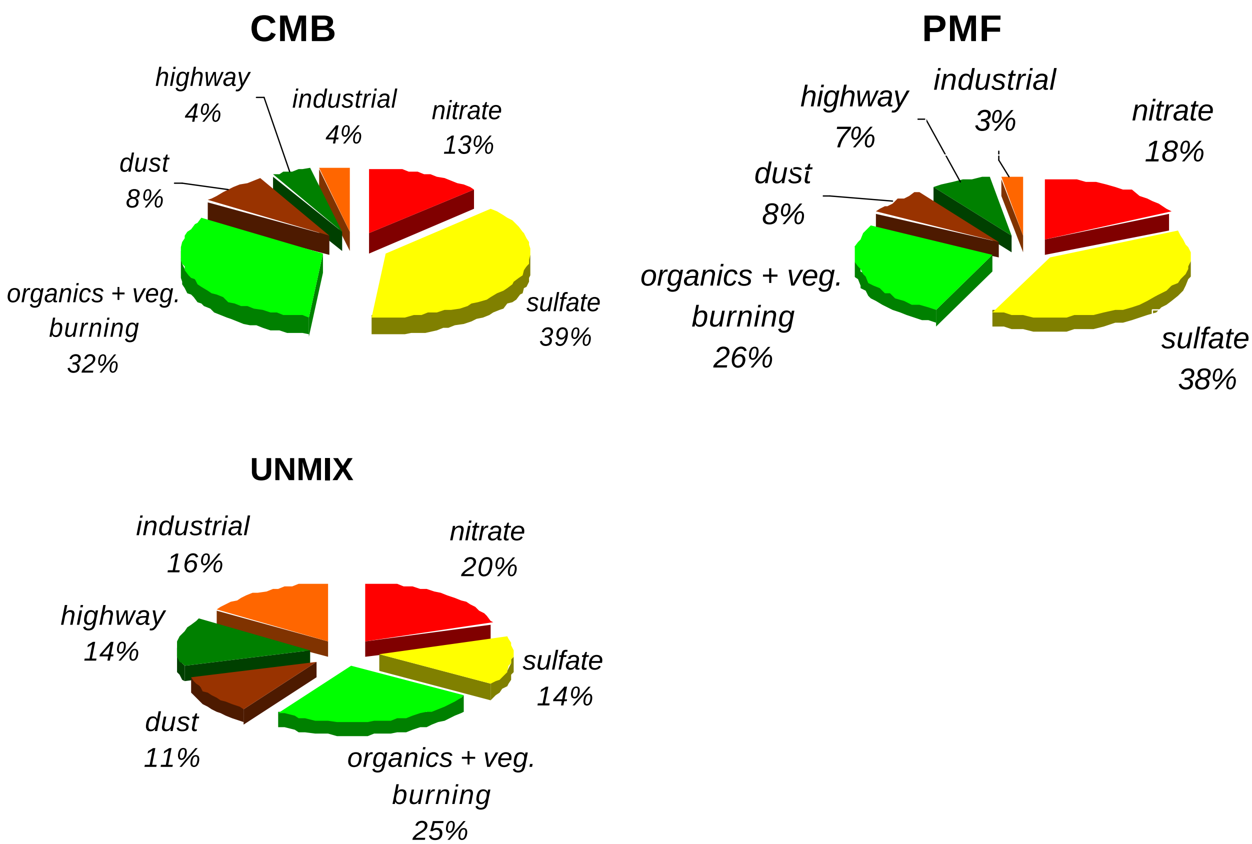


Figure I-8. Source apportionment results from three receptor models for Boundary Waters

Dispersion Modeling Studies: MPCA, CENRAP, and LADCO

Dispersion models were used to estimate source region and source sector contributions for the northern Class I areas. Source contribution information based on the particle source apportionment tool (PSAT) in CAMx is available from several modeling studies: (1) MPCA modeling 2002 and 2018 (MPCA, 2008), (2) CENRAP modeling for 2018 (Environ, 2007), (3) LADCO modeling for 2018 (LADCO, 2006 and LADCO, 2007). MPCA's analyses included 19 source regions, LADCO's included 18, and CENRAP's included 30 (see Figure I-9). All the analyses considered similar source groups: EGU point, non-EGU point, on-road, nonroad, area, and ammonia.

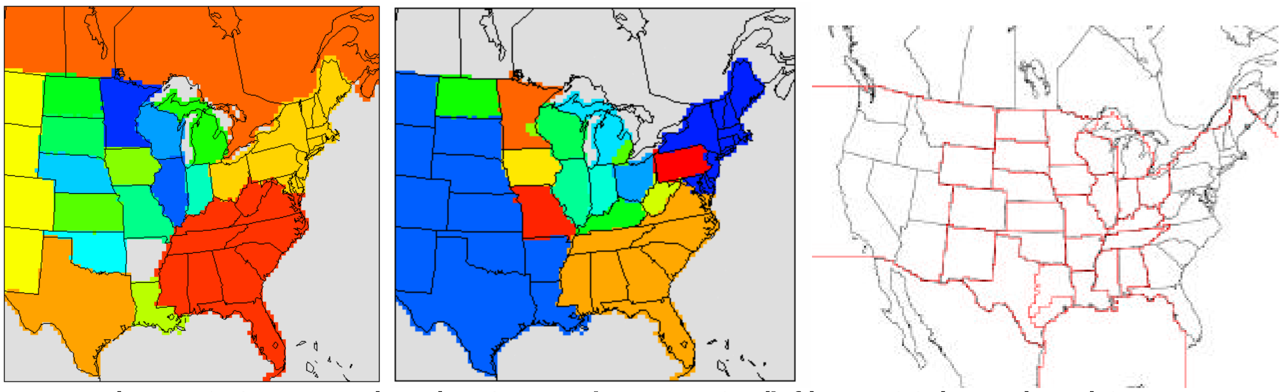


Figure I-9. Source regions in PSAT analyses: MPCA (left), LADCO (center), and CENRAP (right). Contiguous areas of the same color represent a source region.

The contributions to light extinction on the 20% worst visibility days at each of the four Class I areas are shown in Figures I-10 thru I-13. A few comments on these results should be noted:

- Source apportionment differs from source response. The source apportionment results represent how much a given source sector and source region contribute to light extinction, whereas the source response is how much light extinction changes due to changes in emissions from a given source sector and source region.

- The source sector and source region contributions are similar for the base years (2002, 2005) and future year (2018).

- Sulfate impacts are dominated by point source (EGU and non-EGU) SO2 emissions. Nitrate impacts are due to a variety of source sectors.

- The contributions in the two Minnesota Class I areas are dominated by emissions from Minnesota, while the contributions in the two Michigan Class I areas come from several northern and midwestern states.

- CENRAP's modeling shows a higher Canadian contribution compared to LADCO's and MPCA's modeling. This is due to the larger spatial extent of the CENRAP modeling domain, and differences in the Canadian emissions inventory.

Table II-2 provides a summary of the estimated state-level culpabilities based on the LADCO back trajectory analysis and the PSAT analyses for 2018.

Boundary Waters, Minnesota

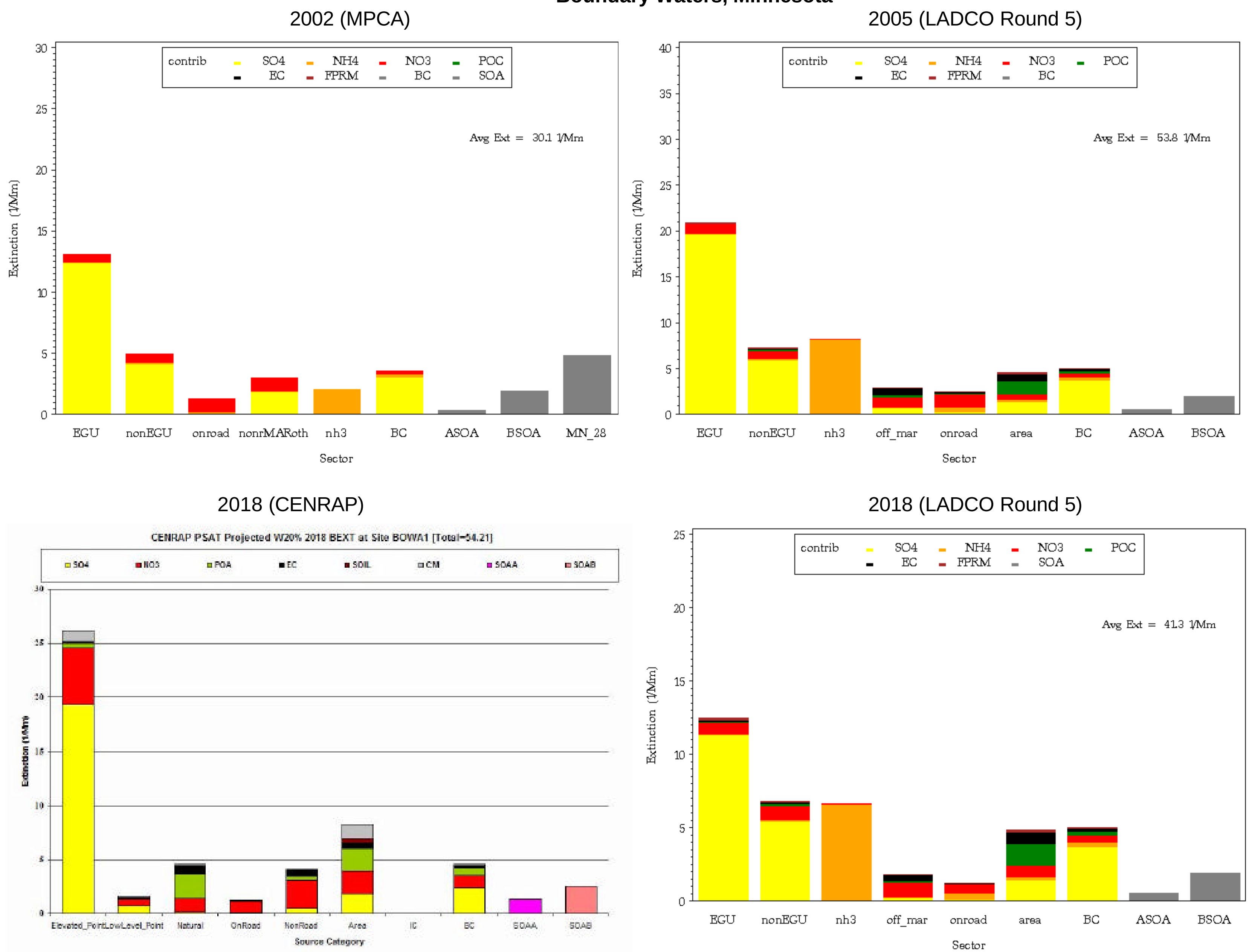
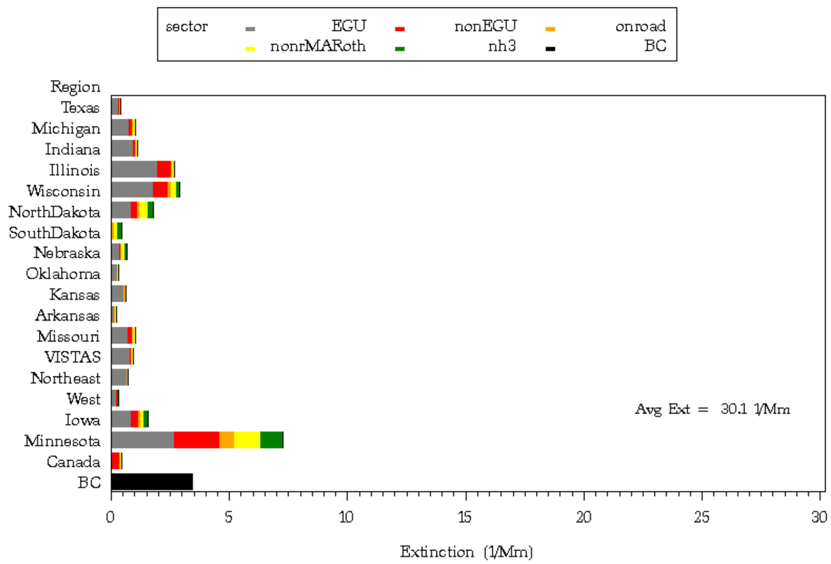


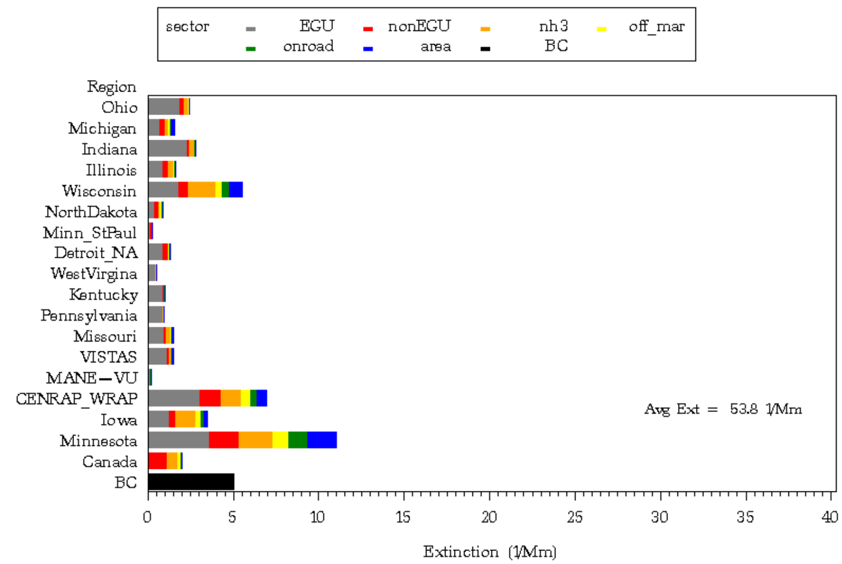
Figure I-10a. Model-based source apportionment for 20% worst days – Boundary Waters

Boundary Waters, Minnesota

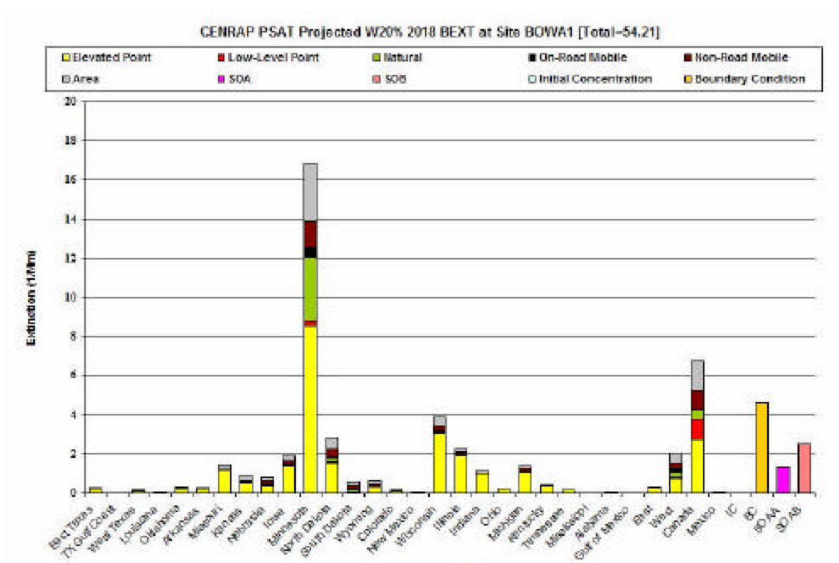
2002 (MPCA)



2005 (LADCO Round 5)



2018 (CENRAP)



2018 (LADCO Round 5)

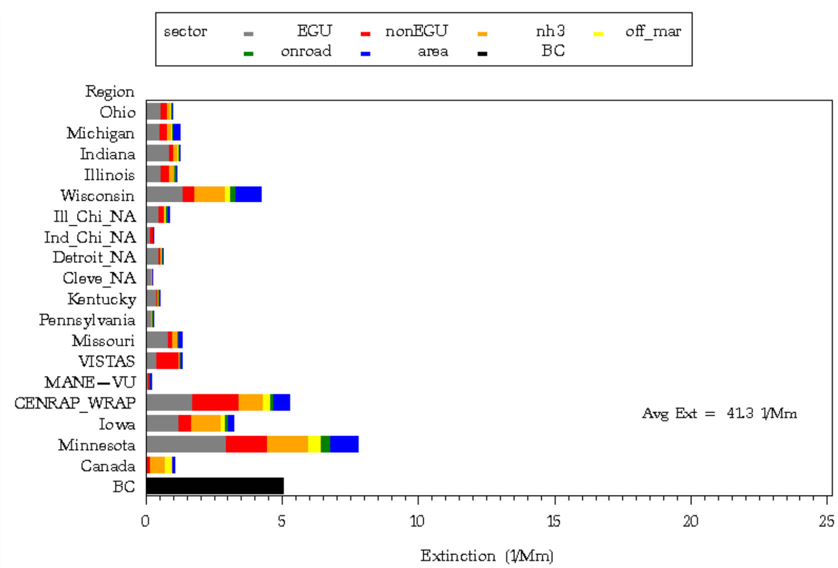
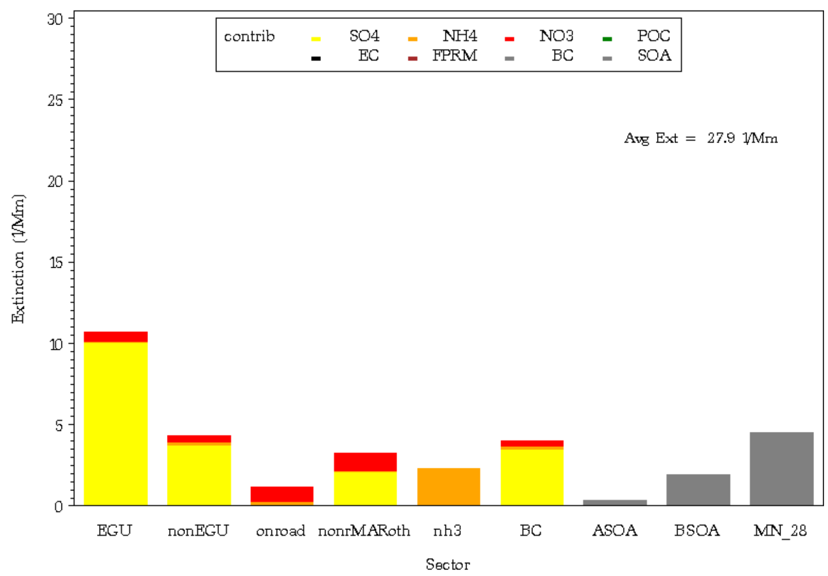


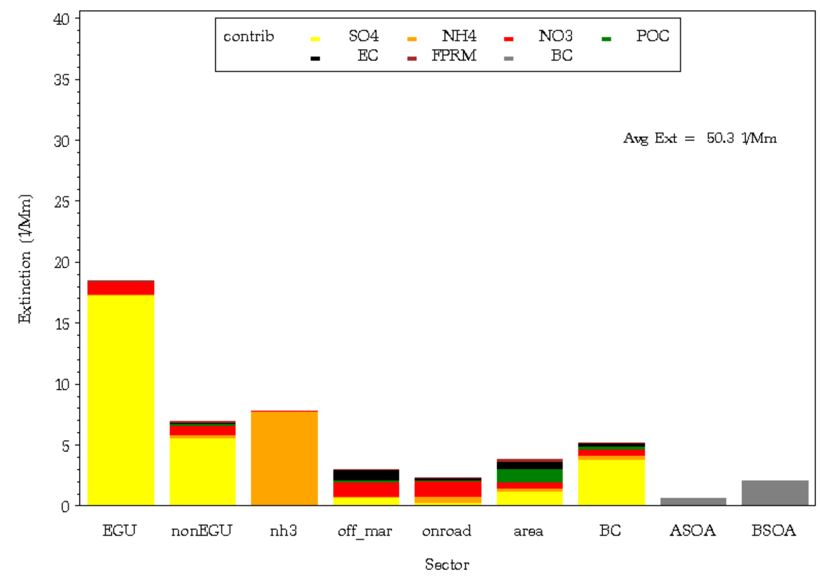
Figure I-10b. Model-based source apportionment on 20% worst days – Boundary Waters

Voyageurs, Minnesota

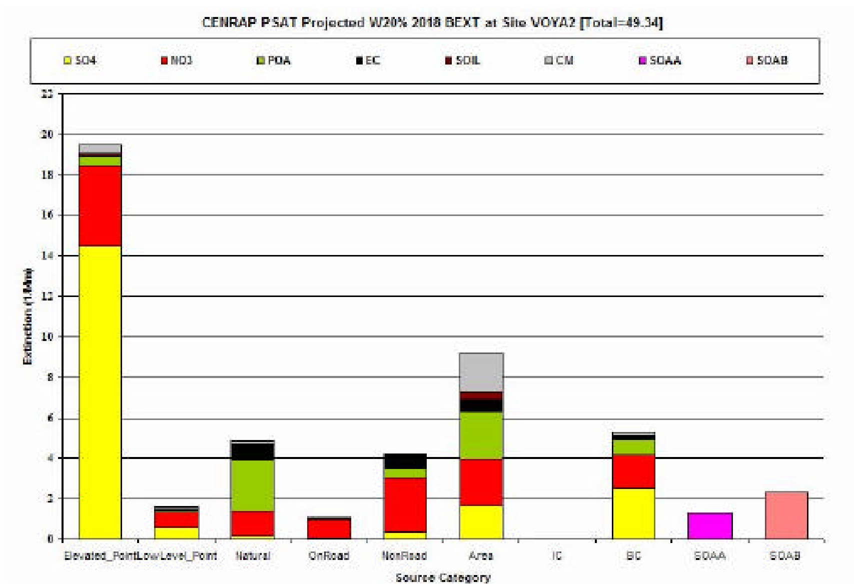
2002 (MPCA)



2005 (LADCO Round 5)



2018 (CENRAP)



2018 (LADCO Round 5)

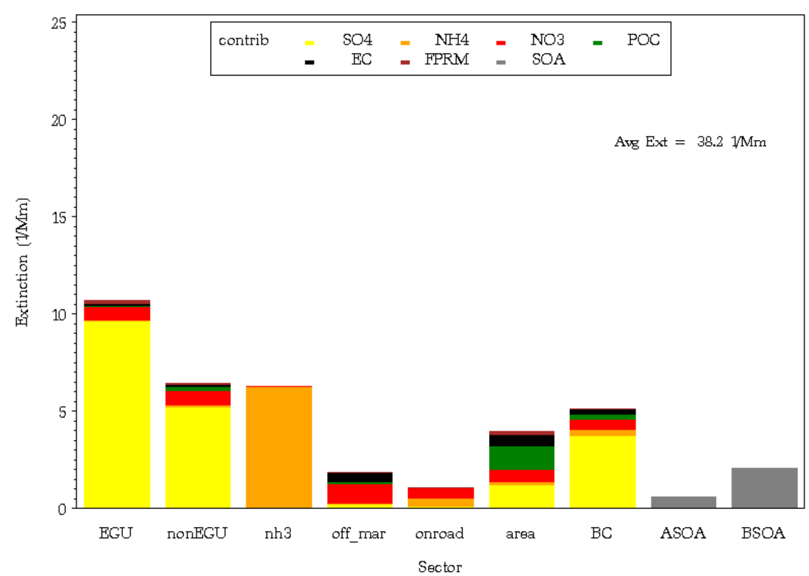
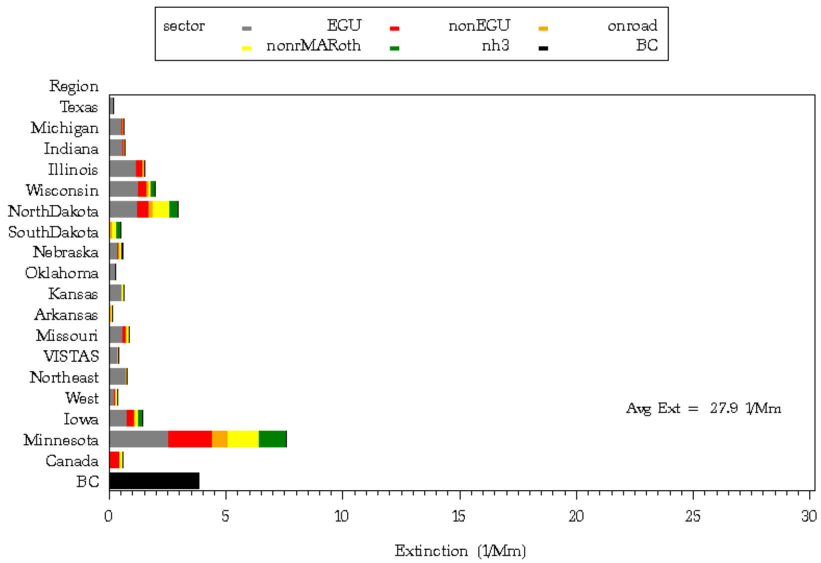


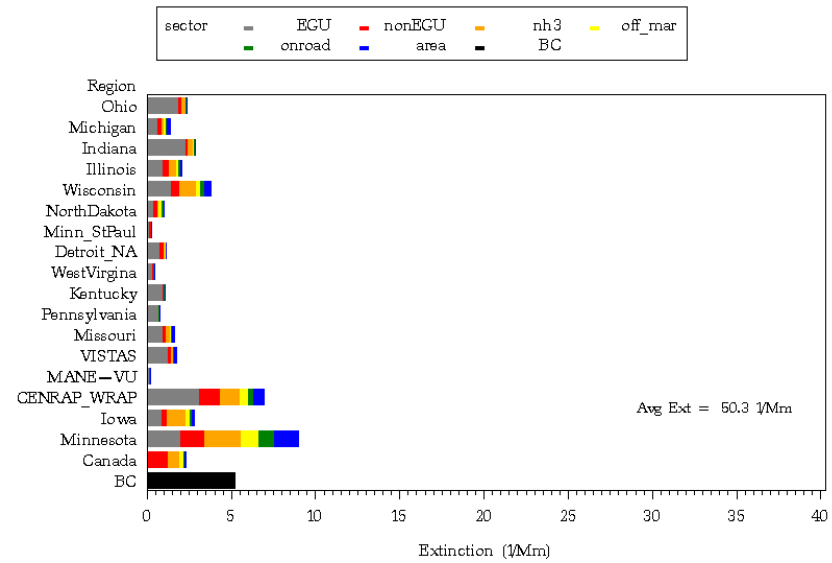
Figure I-11a. Model-based source apportionment for 20% worst days – Voyageurs

Voyageurs, Minnesota

2002 (MPCA)



2005 (LADCO Round 5)



2018 (CENRAP)

2018 (LADCO Round 5)

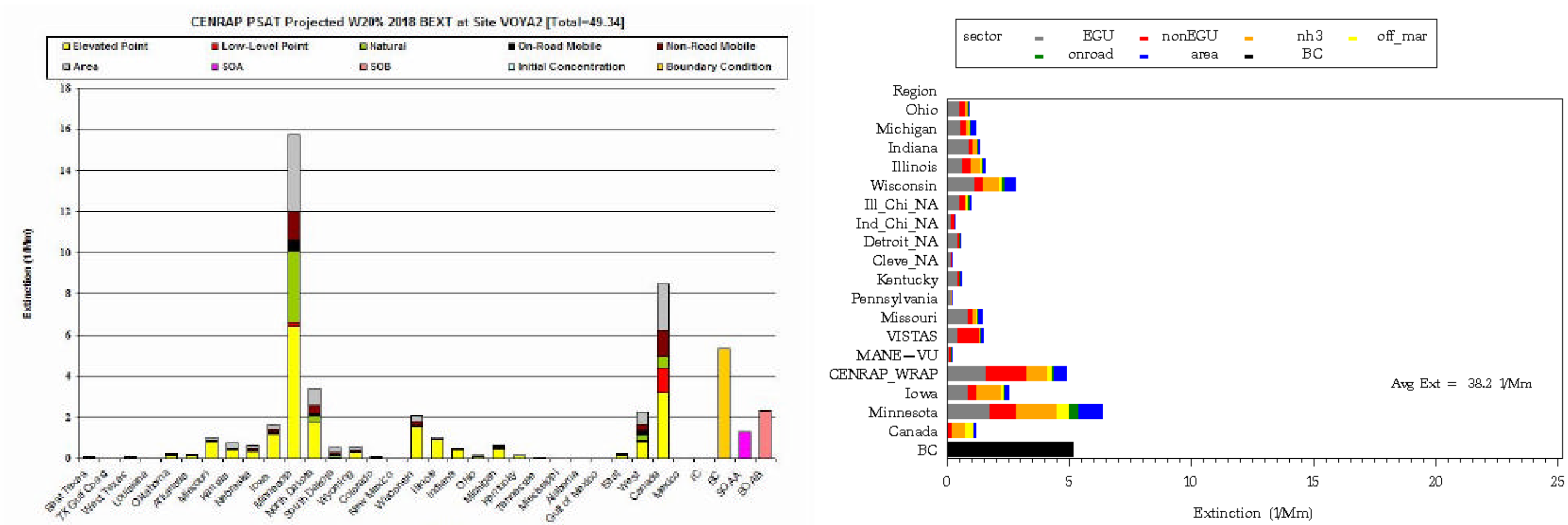
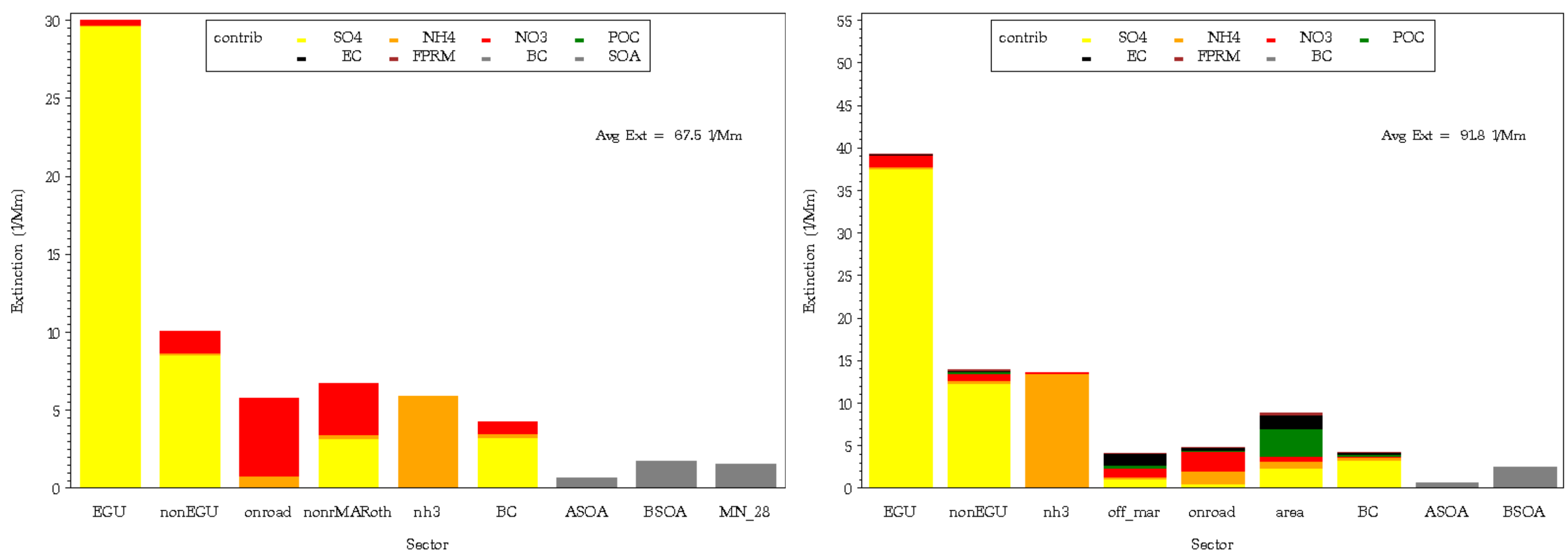


Figure I-11b. Model-based source apportionment for 20% worst days – Voyageurs

Seney, Michigan

2002 (MPCA)

2005 (LADCO Round 5)



2018 (LADCO Round 5)

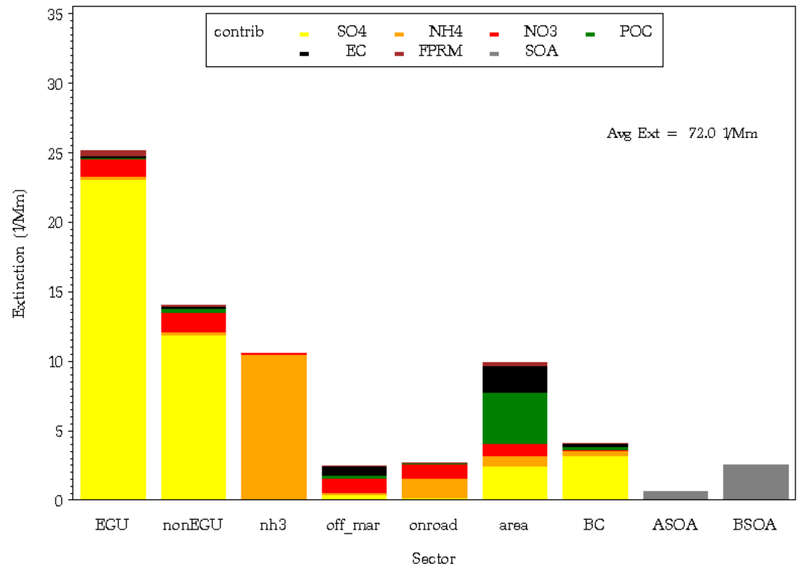
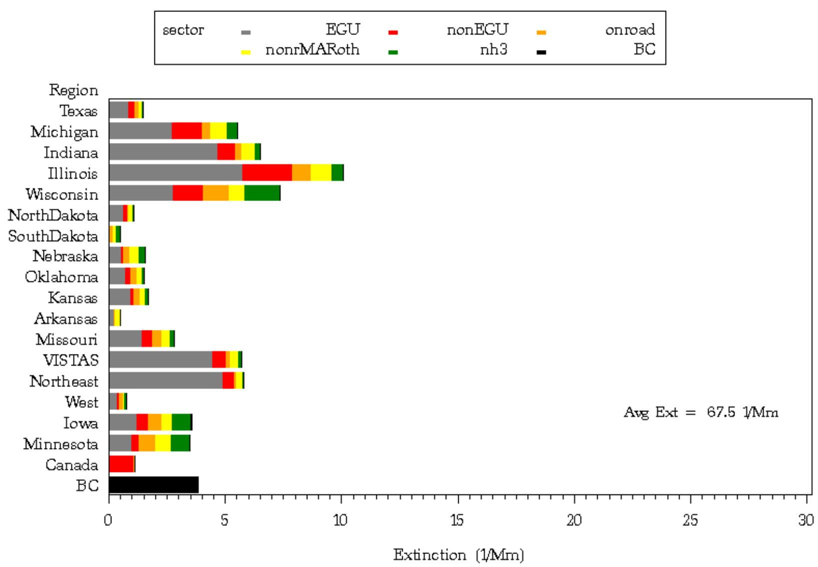


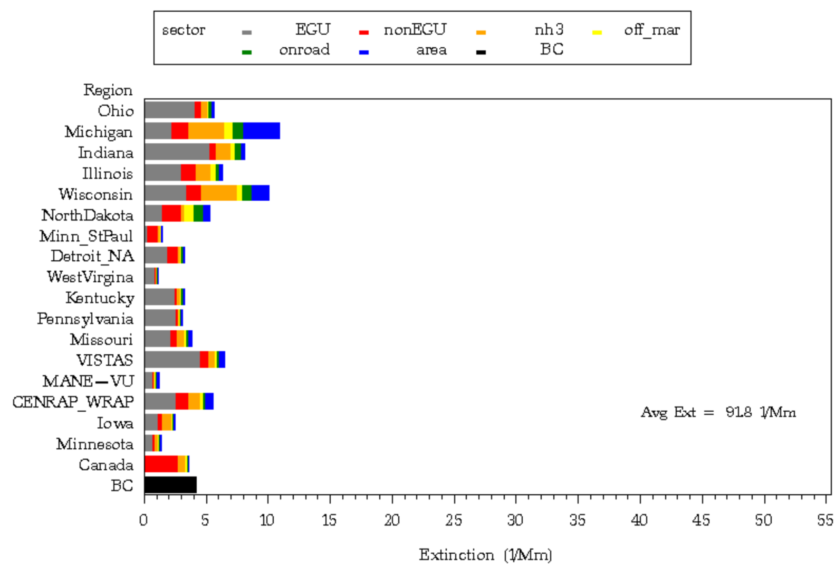
Figure I-12a. Model-based source apportionment for 20% worst days – Seney

Seney, Michigan

2002 (MPCA)



2005 (LADCO Round 5)



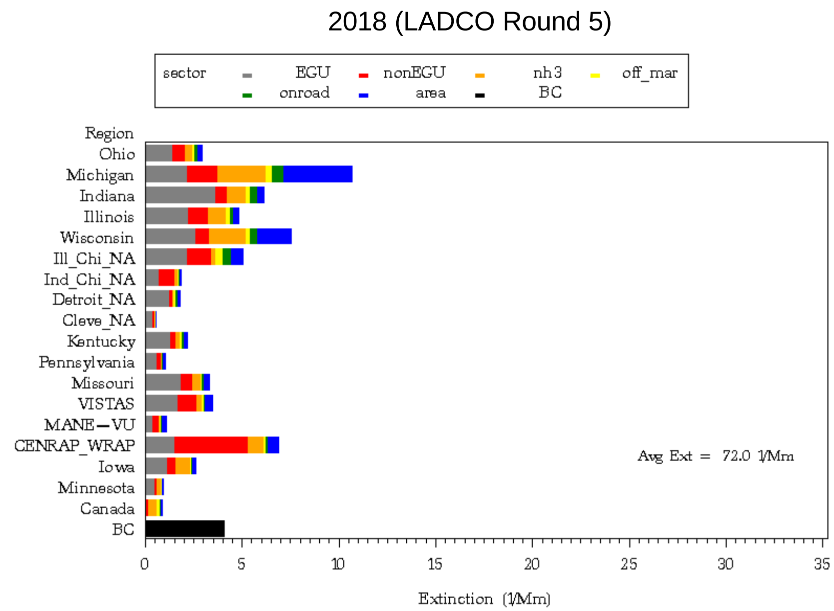


Figure I-12b. Model-based source apportionment for 20% worst days – Seney

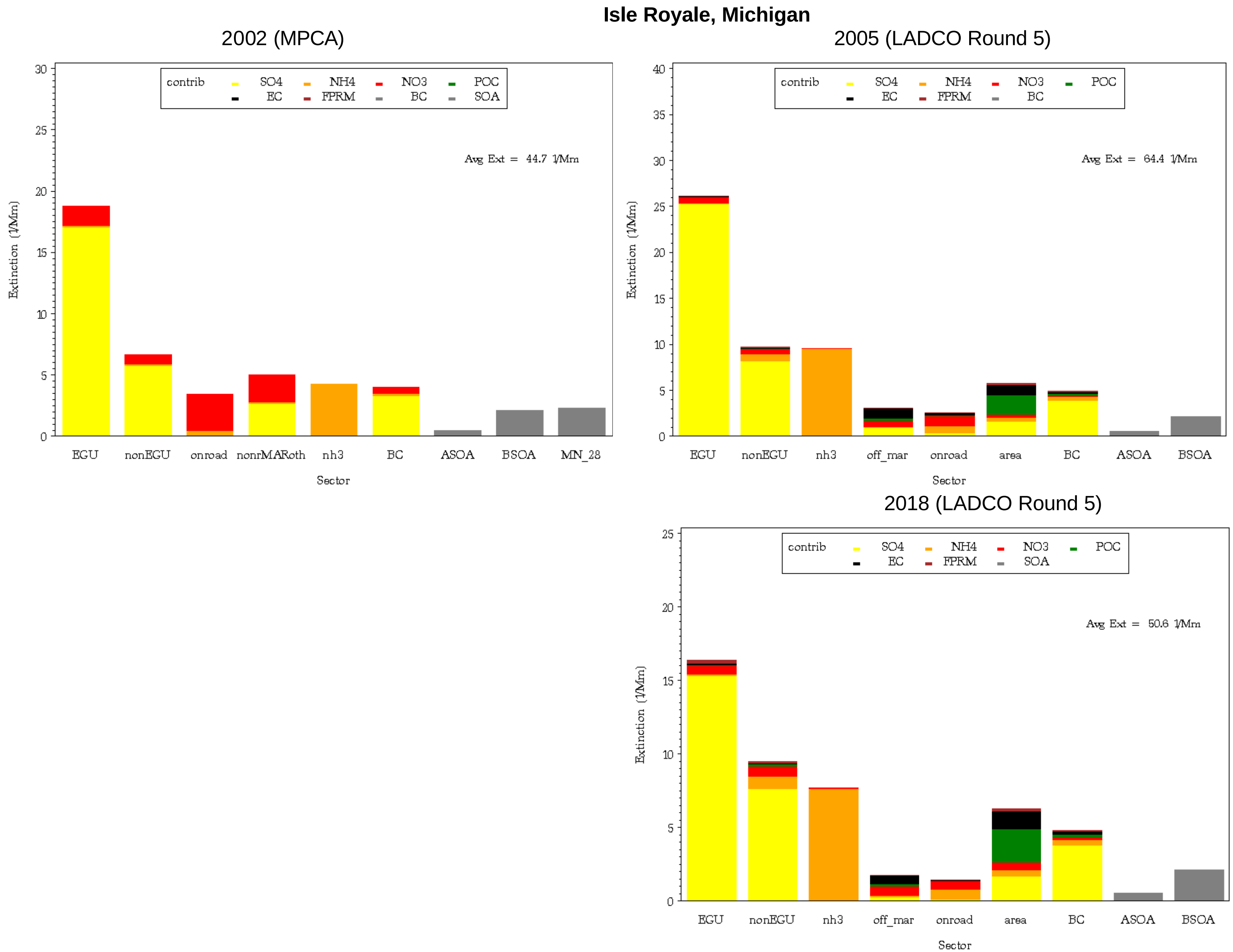


Figure I-13a. Model-based source apportionment for 20% worst days – Isle Royale

Isle Royale, Michigan

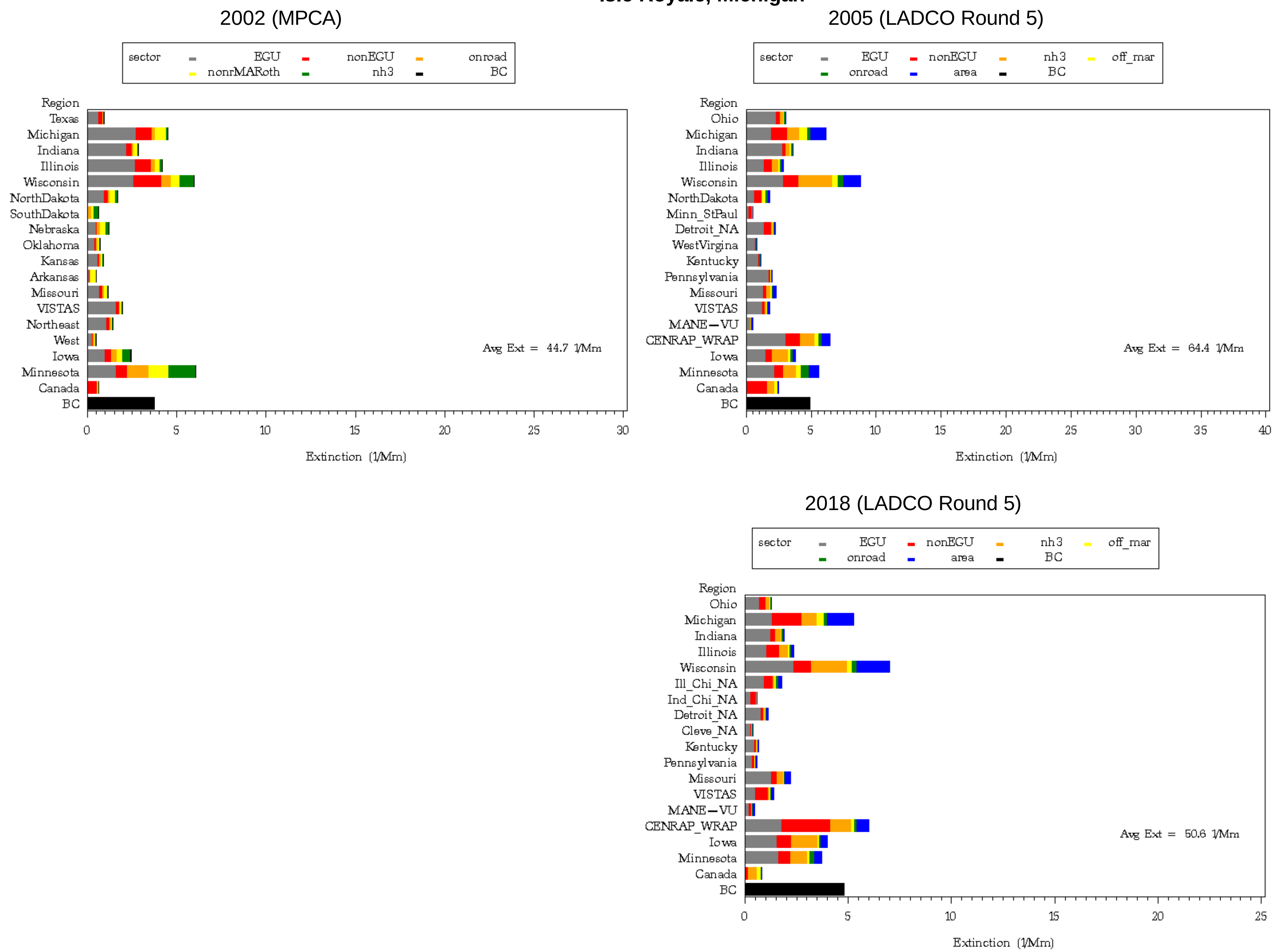


Figure I-13b. Model-based source apportionment for 20% worst days – Isle Royale

Table II-2. State Culpabilities Based on PSAT Modeling and Trajectory Analyses

	Boundary Waters						Seney			
	LADCO - Round 4 PSAT	**LADCO - Round 5 PSAT**	**MPCA-PSAT**	**CENRAP - PSAT**	**LADCO - Traj. Analysis**		**LADCO - Round 4 PSAT**	**LADCO - Round 5 PSAT**	**CENRAP - PSAT**	**LADCO - Traj. Analysis**
Michigan	3.4%	4.8%	3.0%	1.9%	0.7%		13.8%	18.1%		14.7%
Minnesota	30.5%	23.5%	28.0%	30.6%	37.6%		4.8%	1.6%		3.8%
Wisconsin	10.4%	10.9%	10.0%	6.4%	10.6%		12.6%	10.9%		8.4%
Illinois	5.2%	5.1%	6.0%	3.5%	2.7%		13.0%	14.3%		7.4%
Indiana	2.9%	3.9%	3.0%	1.8%	1.2%		9.6%	11.6%		2.2%
Iowa	7.6%	8.3%	8.0%	2.5%	7.4%		6.2%	3.8%		5.7%
Missouri	5.2%	3.4%	6.0%	2.1%	3.3%		6.5%	4.8%		3.2%
N. Dakota	5.7%	1.1%	6.0%	4.6%	5.9%		1.5%	0.1%		0.6%
Canada	1.9%	2.7%	3.0%	12.5%	15.1%		2.1%	1.2%		11.1%
CENRAP-WRAP	10.9%	13.5%		4.2%	10.1%		13.1%	10.0%		7.0%
	83.6%	**77.2%**	**73.0%**	**70.2%**	**94.6%**		**83.3%**	**76.4%**		**64.1%**
	Voyageurs						**Isle Royale**			
	LADCO - Round 4 PSAT	**LADCO - Round 5 PSAT**	**MPCA-PSAT**	**CENRAP - PSAT**	**LADCO - Traj. Analysis**		**LADCO - Round 4 PSAT**	**LADCO - Round 5 PSAT**	**CENRAP - PSAT**	**LADCO - Traj. Analysis**
Michigan	2.0%	4.9%	2.0%	1.0%	1.6%		12.7%	13.4%		
Minnesota	35.0%	20.2%	31.0%	31.5%	36.9%		14.1%	9.5%		
Wisconsin	6.3%	7.9%	6.0%	3.7%	9.7%		16.3%	14.7%		
Illinois	3.0%	7.1%	3.0%	1.8%	1.2%		7.0%	8.7%		
Indiana	1.6%	4.6%	2.0%	0.8%			5.6%	5.2%		
Iowa	7.4%	7.1%	7.0%	2.4%	10.2%		6.9%	8.3%		
Missouri	4.3%	4.0%	4.0%	1.6%	0.3%		3.9%	4.6%		
N. Dakota	10.3%	1.7%	13.0%	6.1%	7.1%		3.6%	0.3%		
Canada	2.7%	3.3%	5.0%	17.2%	13.3%		2.2%	1.7%		
CENRAP-WRAP	10.2%	13.7%		6.1%	16.5%		12.5%	12.6%		
	82.7%	**74.5%**	**73.0%**	**72.2%**	**96.8%**		**84.9%**	**79.0%**		

LADCO Emissions Inventory Comparison

Emissions inventories were examined for the northern states which have the greatest impact on the northern Class I areas: Michigan, Wisconsin, and Minnesota. The sector-level emissions for the base years (2002, 2005) and future years of interest (2009, 2012, and 2018) are presented in Figure I-13 (LADCO, 2006, and LADCO, 2007).[5] The future year SO2 emissions are dominated by EGUs, suggesting that an SO2 emission reduction strategy, which is needed to reduce sulfate concentrations, should focus on control measures for EGUs. The future year NOx emissions come from a variety of sources, suggesting that a NOx emission reduction strategy, which is needed to reduce nitrate concentrations, may need to consider control measures for a variety of source sectors.

Table I-3 provides a summary of the EGU SO2 and NOx emissions for the 2001-2003 period, as well as several 2018 projections (i.e., IPM2.1.9, which was used in the CENRAP modeling and LADCO's Base K/Round 4 modeling, and IPM3.0, which was used in LADCO's Base M/Round 5 modeling).

[5] It is worth noting that the base year (2002) NOx and SO2 emissions for the adjacent Canadian province (Ontario) are considerably less than the combined NOx and SO2 emissions for the three northern states.

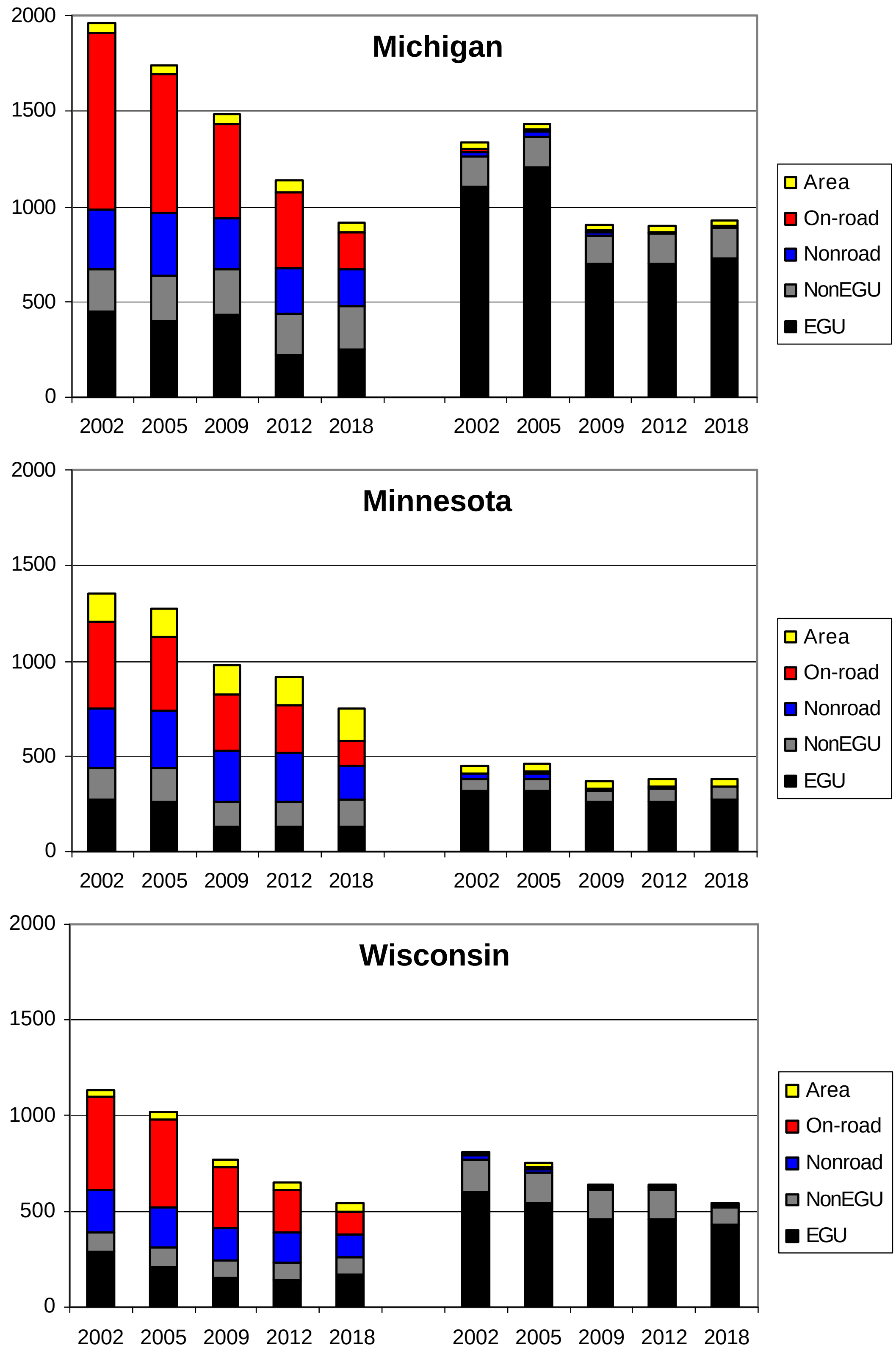


Figure I-13. Emissions for Michigan (top), Minnesota (middle), and Wisconsin (bottom) for NOx (left side) and SO2 (right side)

Table I-3: EGU SO2 and NOx Emissions

	Heat Input (MMBTU/year)	Scenario	SO2 (tons/year)	SO2 (lb/MMBTU)	NOx (tons/year)	NOx (lb/MMBTU)
IL	**980,197,198**	**2001 - 2003 (average)**	**362,417**	**0.74**	**173,296**	**0.35**
		IPM 2.1.9	241,000		73,000	
	1,310,188,544	IPM3.0 (base)	277,337	0.423	70,378	0.107
		IPM3.0 - will do	140,296	0.214	62,990	0.096
		IPM3.0 - may do	140,296	0.214	62,990	0.096
IN	**1,266,957,401**	**2001 - 2003 (average)**	**793,067**	**1.25**	**285,848**	**0.45**
		IPM 2.1.9	377,000		95,000	
	1,509,616,931	IPM3.0 (base)	361,835	0.479	90,913	0.120
		IPM3.0 - will do	628,286	0.832	128,625	0.170
		IPM3.0 - may do	621,539	0.823	127,937	0.169
IA	**390,791,671**	**2001 - 2003 (average)**	**131,080**	**0.67**	**77,935**	**0.40**
		IPM 2.1.9	147,000		51,000	
	534,824,314	IPM3.0 (base)	115,938	0.434	59,994	0.224
		IPM3.0 - will do	115,938	0.434	59,994	0.224
		IPM3.0 - may do	100,762	0.377	58,748	0.220
MI	**756,148,700**	**2001 - 2003 (average)**	**346,959**	**0.92**	**132,995**	**0.35**
		IPM 2.1.9	399,000		100,000	
	1,009,140,047	IPM3.0 (base)	244,151	0.484	79,962	0.158
		IPM3.0 - will do	244,151	0.484	79,962	0.158
		IPM3.0 - may do	244,151	0.484	79,962	0.158
MN	**401,344,495**	**2001 - 2003 (average)**	**101,605**	**0.50**	**85,955**	**0.42**
		IPM 2.1.9	86,000		42,000	
	447,645,758	IPM3.0 (base)	61,739	0.276	41,550	0.186
		IPM3.0 - will do	54,315	0.243	49,488	0.221
		IPM3.0 - may do	51,290	0.229	39,085	0.175
MO	**759,902,542**	**2001 - 2003 (average)**	**241,375**	**0.63**	**143,116**	**0.37**
		IPM 2.1.9	281,000		78,000	
	893,454,905	IPM3.0 (base)	243,684	0.545	72,950	0.163
		IPM3.0 - will do	237,600	0.532	72,950	0.163
		IPM3.0 - may do	237,600	0.532	72,950	0.163
ND	**339,952,821**	**2001 - 2003 (average)**	**145,096**	**0.85**	**76,788**	**0.45**
		IPM 2.1.9	109,000		72,000	
	342,685,501	IPM3.0 (base)	41,149	0.240	44,164	0.258
		IPM3.0 - will do	56,175	0.328	58,850	0.343
		IPM3.0 - may do	56,175	0.328	58,850	0.343
SD	**39,768,357**	**2001 - 2003 (average)**	**12,545**	**0.63**	**15,852**	**0.80**
		IPM 2.1.9	12,000		15,000	
	44,856,223	IPM3.0 (base)	4,464	0.199	2,548	0.114
		IPM3.0 - will do	4,464	0.199	2,548	0.114
		IPM3.0 - may do	4,464	0.199	2,548	0.114
WI	**495,475,007**	**2001 - 2003 (average)**	**191,137**	**0.77**	**90,703**	**0.36**
		IPM 2.1.9	155,000		46,000	
	675,863,447	IPM3.0 (base)	127,930	0.379	56,526	0.167
		IPM3.0 - will do	150,340	0.445	55,019	0.163
		IPM3.0 - may do	62,439	0.185	46,154	0.137

Other Issues: Transboundary Impacts

In a Technical Brief, EPRI proposed an alternative method for calculating future year visibility impacts in the northern Class I areas (EPRI, 2007). This method subtracts the transboundary impact from the 2018 future year visibility estimate and compares this adjusted future year value to the uniform rate of improvement value.

In a letter to EPRI dated July 20, 2007, LADCO cited two major concerns with EPRI's analysis (i.e., transboundary impact is flawed because it is based on VISTAS' modeling which relied on a bad version of the Canadian emissions inventory, and adjustment of only the 2018 visibility value is inconsistent). In addition, LADCO noted that technical analyses (e.g., LADCO's back trajectory analyses using 2000-2005 data) show that visibility impairment on the 20% worst visibility days is dominated by emissions from sources in the U.S., and are not greatly affected by transboundary impacts.

In a follow-up letter dated July 31, 2007, EPRI stated its belief that the emissions inventory problems may actually understate (not overstate) the Canadian contribution, and that its approach to only adjust 2018 values was a "reasonable way to examine the influence of transboundary pollution".

Putting aside the EPRI analysis and its criticisms, the fundamental issue is to what degree Canadian emissions are impacting visibility on the 20% worst visibility days in the northern Class areas[6]. There appear to be two principle pieces of information which address this issue:

- Back Trajectory Analyses: The contoured trajectories (Figures I-1 through I-4) show that, generally, bad air days are associated with transport from the south, and good air days with transport from Canada. As noted above, however, the detailed trajectories (Figure I-5 and I-6) show that a few of the worst-day trajectories originate in Canada. Nevertheless, many of these trajectories actually spend significant time in the U.S. and should not be thought of as strictly Canadian influences.

- PSAT Analyses: There are two fundamental differences between the MPCA/LADCO and CENRAP PSAT analyses: (1) extent of modeling domain (see Figure I-8), and (2) version of the Canadian emissions inventory. On the first point, the CENRAP domain is better, given that it includes much of the southern Canadian provinces, whereas the MPCA/LADCO domain only includes portions of some of these provinces (i.e., Saskatchewan and provinces to the east). On the second point, LADCO's Base M/Round 5 analysis is better, given that it reflects the most current version of the Canadian emissions inventory (including stack parameters). (Note, however, LADCO's modeling may overstate the 2018 Canadian contribution, because it assumed 2018 and 2005 emissions are the same.)

[6] In a guidance memo, USEPA has stated that "States should not directly consider the effects of international emissions when calculating their uniform rates of progress by either adding the effects of international emissions to their estimates of natural conditions, or by subtracting international emissions from current conditions. Either of these approaches conflicts with the basic definitions of "current conditions" (baseline conditions for the first SIP) and "natural conditions," as described in the 1999 RHR. 64 Fed. Reg. 35728, (July 1, 1999)." (USEPA, 2006)

In conclusion, while the back trajectory analyses suggest the impact from Canadian sources in the northern Class I areas is small, there is sufficient uncertainty with the available modeling analyses that it is not possible to estimate, with any confidence, their impact. Further analyses may be warranted to quantify the Canadian contribution. In particular, an analysis should be conducted using the most current version of the Canadian emissions inventory (with up-to-date stack parameters) and an expanded CENRAP-like modeling domain.

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